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Research Article

Potential of jute fiber-reinforced composites in the manufacture of components and equipment used on ships and hulls

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Abstract. In today's maritime field, metal materials are very popular, but they have certain limitations. To meet a variety of requirements, many new materials have been used, including fiberglass reinforced composites, but these materials are often difficult to decompose, have poor recyclability, and cause a great impact on the environment after a period of use. There have been many studies aimed at using natural fibers to replace glass fibers in order to solve the limitations of glass fiber reinforced composites. Jute is one of the most popular natural fibers. Recently, researchers have focused their attention on jute fiber-reinforced composites. This article will talk about the potential of jute fiber reinforced composites applied to the manufacture of components and equipment used on ships and hulls.

Keywords: Jute fiber; Natural fibers; Composites, Shipbuilding

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1. Introduction

Currently, sea transportation is critical to global commodities commerce (Suárez-Alemán, 2015)(Park et al., 2021)(Ghaderi, 2019). Global logistics operations are thriving and expanding, with sea transit accounting for 80% of global commodities trade. Many shipping firms and fleets of countries throughout the world have been founded to serve this expansion. As a result, fuel demand is skyrocketing. The emissions from marine diesel engines are often emitted directly into the environment, producing contamination (Hoang & Pham, 2018)(Chau, Nguyen, Do, & Le, 2020)(Hoang et al., 2018). Many research has been conducted to find a solution to the issue, including the search for a reasonable alternative fuel, the improvement of diesel engine efficiency through various approaches (X. P. Nguyen et al., 2020)(X. P. Nguyen & Hoang, 2020)(Hoang, 2020), methods for feasible emission reduction (H. P. Nguyen et al., 2021)(Hoang, 2018), advanced technologies implementations (Pham & Hoang, 2020)(Van & Anh, 2019)(Chau, Le, Hoang, Al-Tawaha, et al., 2020), and hypothetical research solutions on fluid motion associated to vessel motion (Chau, Nguyen, Do, & Nguyen, 2020)(Chau, Do, Le, Nguyen, et al., 2020)(X. P. Nguyen, 2020). Simultaneously to this, several container vessels have been designed to meet the high demand for worldwide commerce (Peters, 2001)(Prokopowicz & Berg-Andreassen, 2016)(Tillig & Ringsberg, 2020). Nevertheless, the consequences include unsustainable, unbalanced, and a direct harmful influence on the marine ecosystem. The contamination of the maritime environment is rising, and the largest source of emissions at sea is marine transportation. Ships pollute the environment through emissions, oil spills, heavy metals, and cargo. This problem also provides significant concerns to environmental safety. CO2, NOx, and other exhaust gases have a harmful influence on the atmosphere. The drop of these gases may be readily observed in the present CoVid-19 era, and numerous studies suggest that the atmosphere is becoming cleaner (H. P. Nguyen et al., 2021)(X. P. Nguyen, Hoang, Ölçer, et al., 2021)(Aktar et al., 2021)(Hoang, Huynh, et al., 2021). Furthermore, clever control systems for successfully reducing hydrocarbon and carbon monoxide emissions from diesel engines diminish hazardous pollutants released by ships (Vinayagam et al., 2021)(Ravi & Pachamuthu, 2020). Ballast water is another type of emissions from ships that has a direct impact on the maritime ecology. Ballast water can be discharged or released to maintain the stability of a vessel, depending on the goods transported. The ballast water of a ship may include oil from an oil spill or a leak from the vessel's storage areas. This issue is addressed by various technical methods such as the use of various kinds of absorbing materials (Phan et al., 2018)(Holley et al., 2021)(Rowinski et al., 2021), absorbent material-based equipment (Hoang, Nguyen, et al., 2021), and so on. Presently, the influence of the Covid-19 epidemic is causing the worldwide energy system to shift toward the application of renewable energy and biofuels, which decreases harm to the environment dramatically (X. P. Nguyen, Hoang, I.Ölçer, et al., 2021)(Hoang, Sandro Nižetić, et al., 2021)(X. P. Nguyen, Le, et al., 2021)(Huynh et al., 2021)(Xuan et al., 2021). Furthermore, microorganisms in ballast water might be transported from one location to another. When disposal occurs far from an organism's native range, there is the possibility of non-native organism's establishment and invasion. According to Molnar et al. (Molnar et al., 2008) and Saebi et al. (Saebi et al., 2020), global commercial shipping transports more than half of all marine exotic species, and

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ballast water is projected to transfer 10,000 organisms (Bax et al., 2003). Several studies have found that exotic species have harmful consequences on the environment, economic activity, and human health (Ruiz & Carlton, 2003)(Chan et al., 2019)(Lovell et al., 2006)(Wan et al., 2016)(Wan et al., 2018)(David et al., 2019). Heavy metals and non-biodegradable debris, like as plastic, can also be found in ballast water. When discharged into the ocean, it has a negative impact on the marine ecology; several research have been conducted to address this issue (Hoang et al., 2022)(Upadhyay et al., 2021)(Chau, Hoang, Truong, & Nguyen, 2020)(Bai et al., 2019)(Hoang & Pham, 2021). The material used to make the equipment and hull is also an important issue. Currently, familiar materials such as wood, metal, etc. are often used. However, these materials are increasingly scarce. Synthetic materials are an interesting alternative.

Composite materials must be manufactured by merging various property material types. The composite has very high specific strength as mechanical strength, strength/weight ratio, as well as the lowest thermal expansion, etc. Because of this preeminent property, composite materials have become one of the new leading types to be studied, manufactured and applied instead of traditional types. Nowadays, with material technology advancement, scientists aim to research utilizing biodegradable materials in general technical applications (Thyavihalli Girijappa et al., 2019)(Khalid et al., 2021)(Sanjay et al., 2018). The material must have characteristics of biodegrade-ability and remarkable mechanical properties. This material would be one type of eco-friendly and multifunction-applications (M.R. et al., 2019). The material matching this requirement firstly mentioned should be natural fibers-used as reinforcement to polymers because of their good strength, low cost, plentiful availability, and less effect on the environment (Khalid et al., 2020). Now, Enhancement of the technical properties of polymer composite materials is one of the common applications of natural fibers.

The material source of composite reinforcement could be developed from plants, such as cotton, flax, kenaf, hemp, jute, sisal, pineapple, ramie, bamboo, bananas, etc., and wood, which are conventional lingo for cellulosic fibers, nowadays used more widely. They possess many good advantages to becoming an attractive ecological option to replace glass, carbon and man-made fiber in composite manufacturing, such as availability, low density, renewability, and reasonable cost, as well as satisfactory mechanical properties (Sai Shravan Kumar & Viswanath Allamraju, 2019).

Jute plants are popularly and abundantly grown in Bangladesh, China, India, Thailand, and the UK. Jute trees with a trunk diameter of about 25mm are stripped of their bark to collect jute fibers. Obtaining mature jute plants, bundling them together and immersing them in water for around 4 weeks in order to have them completely decomposed and fibers exposed. Finally, the fibers are separated from the stem, washed and dried using sunlight (Mansur & Aziz, 1982). When compared to traditional glass fibers, the low specific gravity and high specific modules of jute fibers (40GPA for jute fibers and 2.5 and 30GPA for glass fibers respectively) are outstanding advantages that make them able to partially or completely replace glass fiber to strengthen composite materials. However, jute fiber has lower tensile strength and Young's module than glass fiber. Otherwise, the specific modulus of jute fiber is much higher than glass fiber's on the relatively more hydrophobic matrices. Researching the life cycle assessment of Jute reinforced composites evidenced that their environmental performance is more preeminent than that of glass fiber composites (Alves et al., 2010). Refer to Alves et al., the specific properties of jute fibers are the following: density: 1.5 g/cm3; tensile strength: 393-773 MPa; elastic modulus: 10-30 GPa. So jute fiber has become the most familiar type.

Epoxy resin is one type of thermosetting resin and is widely used in industries, especially aerospace, automobile and marine. With a hydrophilic nature, this material is particularly useful when composites are strengthened by natural fiber reinforcement because of their high affinity for these types of fibers. Based on the strength properties of jute fibers and their compatibility with polymers, a range of composites consisting of jute-epoxy, jute-polyester, jute-phenol formaldehyde, and jute-polypropylene have been manufactured and used in various areas, for example as low-cost housing elements, silos for grain storage, and small fishing boats (Satyanarayana et al., 1990). This paper presents an overview of the properties of jute fiber reinforced composites. It also shows the potential applications of this material in the manufacture of ship parts and hulls as an alternative to fiberglass reinforced composites in the shipbuilding industry.

2. Properties of jute fiber-reinforced composites

The properties of jute fiber-reinforced composites have been shown in a series of studies, and are continuously improved to meet application requirements. Shah and Lakkad (Shah & Lakkad, 1981) carried out many experiments to evidence that jute fibers are suitable to be used as reinforcement fibers replacing glass fibers and polymer resins as well as in cases requesting modest strength and modulus. They measured that the tensile strength of the jute fiber fortified epoxy resin composite created was 104 MPa, and Young's modulus was 15,042 Gpa (Shah & Lakkad, 1981). Other experiments conducted by Kumar (P. Kumar, 1986) applying an suitable formula of mixture, jute fiber reinforced epoxy composite materials withstand higher tensile properties (271 MPa of tensile strength and 39.1 GPa modulus). Although the tensile characteristics of jute fiber fortified polymer composite is assuredly underperforming to that of glass fiber reinforced polymer composite, they have a much higher competitive advantage on the economic side.

The polypropylene matrix is the most often used thermoplastic with jute fibers because to its competitive prices, low thermal expansion, and recycling potential (Bowman et al., 2018)(Shubhra et al., 2013). Physiochemical treatment can increase the adherence of hydrophilic jute fibers. Mechanical treatment comprises the application of plasma, steam, ionizing radiation, and so on, whereas chemical treatment entails the application of alkali, acetylation, maleated coupling agents such as maleic-anhydride grafted PP, silane coupling agents, and so on**. Table 1** summarizes the mechanical parameters of jute polypropylene composites.

In other experiments on jute fibers by Gassan and Bledzki (Gassan & Bledzki, 1997), a coupling agent was used to modify the fibers in order to increase the dynamic modulus by 20 percent, the fatigue limits by 20 percent, and decrease the moisture absorption by 10 to 20 percent. However, this added agent made tensile properties reduced by up to 30 percent. Later on, by using sodium hydroxide (NaOH) alkali for pre-treating fibers in material fabrication, other scientists (Gassan & Bledzki, 1999) found a way to improve the mechanical properties of jute fiber reinforced epoxy composites. They measured that tensile strength increased by 120 percent and modulus by 150 percent in the alkali-treated fiber compared with the untreated fibers. Finally, treated jute fiber reinforced composite materials also positively improved the tensile properties due to increased mechanical properties after treatment of jute fiber. The acrylation of alkali-treated jute fibers affected the mechanical and electrical properties of jute fiber-reinforced composites. The studies of Patel and Parsania (Patel & Parsania, 2010) indicated that it increased 42.2 percent in tensile strength, 13.9 percent in flexural strength, 400 percent in electrical strength, and 123.5 percent in volume resistivity.

Table 1. Mechanical properties of coir polymer composites

Fiber Content (wt %)	Chemical treatment	Processing	Tensile strength (MPa)	Tensile modulus (MPa)	Flexural strength (MPa)	Flexural modulus (MPa)	Impact Strength (J/m)	References
15	2 wt% Silane	Internal mixer and injection molding	37	2200	-	-	-	(Hong et al., 2008)
30	0.5% MAPP, 5 min time	Mixing in two-roll mill and compression Molding	31.27	-	59.18	-	65.96	(Mohanty et al., 2004)
30	2 wt% MAPP	Extrusion and injection molding	56.71	1820	77.32	4340	-	(Anjali Singh & Palsule, 2016)
30	5 wt% Alkali	Twin screw extrusion and injection molding	27.32	2630	-	2737	81	(Chandekar et al., 2020)
	KMnO4	-	29.52	2822	-	2705	84	
	2 wt% Silane	-	26.97	3026	-	2757	75	
50	3 wt% MAPP coupling agent	Kinetic mixer and injection molding	59.13	7560	87.66	10,520	-	(Karmaker & Youngquist, 1996)

The possibilities for improving the mechanical properties of jute/epoxy composites by alkali treatment of fibres were presented in the experiment report by Jochen Gassan et al. (Gassan & Bledzki, 1999). This study aimed to prove how to improve the mechanical properties of natural-fibre-reinforced thermosets. If using a NaOH-treatment process with different alkali concentrations and shrinkages, it will optimize the mechanical properties of jute fibers. The treatment process causes shrinkage of the fibers, which has the most significant impact on the fiber structure, and then effects changes to the fiber mechanical properties such as tensile strength, modulus, and toughness. The Jute-epoxy composite could be fabricated by a manual lay-up technique-tried by Seki (Seki, 2009). Tensile, flexure and short beam shear tests also determined the effect on mechanical properties of the alkali treated jute fibers with oligomeric siloxane. Surface treatment by alkali, organosilane, epoxy dispersions and their combinations-tried by Doan et al. (Doan et al., 2012). They showed that these treatments on jute fibers increased the adhesion strength, which was measured by wettability and a single fiber pull-out test in an epoxy matrix. Also, using the manual lay-up method in the fabrication of jute-epoxy composites, Raghavendra et al. (Raghavendra et al., 2017) researched their moisture absorption characteristics if affected by saline, mineral and sub-zero temperature water and determined their tensile and flexural strength.

According to Wang et al. (Wang et al., 2019), most of the jute fiber composites outperformed the plain epoxy one in terms of tensile strength (>43 MPa). Tensile strength appears to improve with fiber weight fraction in both the raw jute composite and the treated jute composite. The maximum strength of an object is the greatest load that a material can withstand before failing. Because the composites include unidirectional fibers, the tensile strength difference might be attributable to another critical factor. Normally, the fiber characteristics have the greatest effect on the properties of unidirectional composites evaluated in the fibre orientation. As a result, in this work, we examined the tensile characteristics in the fibre orientation. Nonetheless, the tensile strength of treated jute fiber composites was reported to be greater in comparison with that of pure jute fiber composites as shown in **Figure 1**.

The moisture absorption by composites will be reduced under the fiber treatment of Ethylenediamine (EDA), but it does not cause disadvantages to the tensile strength and modulus of jute-polyester composites. After treatment, compared with the untreated sample, the respective results of tensile strength and modulus were still measured at 143.5 MPa and 6.9 GPa and 153.4 MPa and 8.4 GPa. They discovered that the moisture absorption levels increase with increasing volume fraction of jute fibers under constant humidity and ambient conditions, so this impregnation process of fibers will decide the moisture absorption of jute-polymer composites. Jute fibre reinforced Epoxy composite properties can also be concluded from studies by Asheesh Kumar (A. Kumar & Srivastava, 2017). The jute epoxy possessed higher tensile and compressive strength. The bundle strength of fibres increases if the number of fibres in a bundle decreases. Bending strength and compressive strength also have a direct proportion with the percentage of jute fibers. Tensile strength increases with reinforcement by Jute fibers. The figure of impact strength does not have any significant effect by adding fibers. The surface of jute fibers could be treated by different methods, such as silane treatment, alkali treatment, and silane and alkali treatment, and their corresponding jute fiber-reinforced composites with epoxy resin as a matrix to study their thermal and mechanical properties using vacuum-assisted resin infusion (Liu et al., 2010). Another study used two kinds of finishing agents for textiles, micro-silicone and fluorocarbon, in order to improve the surface properties of jute fabric-reinforced composites with a polyester matrix and their flexural, tensile, and interlaminar shear strength were analyzed (Dilfi K.F. et al., 2018).

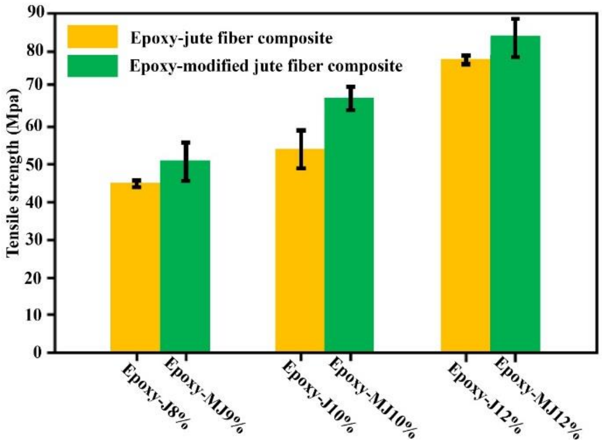

Figure 1. Effect of fiber loading on the tensile strengths of the modified composites (Wang et al., 2019)

3. Potential of jute fiber-reinforced composites

Boats with hulls made of fiber-reinforced composites of less than 20 meters in length are very popular today. In the saline climate, wood/steel is very prone to deterioration, hence the boats must be maintained on a regular basis. Therefore, with improved properties of impact resistance, flexural strength, and corrosion resistance, composite boats absolutely have the ability to stand severe slamming by tidal waves without heavy damage like wood boats. They also have a working life of about 12-15 years-much longer than the 3 years of the wooden ones. In the case of unforeseen calamities like tsunamis, most of them could be repaired and re-used quickly.

Jute-reinforced composites can be used for onboard equipment such as seats, desks, showers, shower equipment, etc. They are also easily applied as covers for electrical equipment, pipelines, load-bearing structures, bulkheads, containers, etc. on ships. For jute-reinforced composites to be applicable in the shipbuilding industry, much research and new techniques are needed to achieve the same specifications as those of glass-fiber reinforced composites. There have been many studies using new techniques to improve the mechanical properties of jute fiber-reinforced composites to meet the structural strength of the hull details of ships. The studies listed below show the potential of jute-reinforced composites.

Composite boats using fiber reinforced make more reliable points of structure. This is an advantage of this material (Neşer, 2017)(Balan & Ravichandran, 2020). About sound absorption property, research also showed that treated jute fiber has less acoustic performance than untreated fiber at the frequency span of 1-4 kHz (Fatima & Mohanty, 2011). The experiment of L. Yuvaraj et al. 2021 (Yuvaraj et al., 2021) indicated that if making perforations in jute composite panels, they will affect significant sound-absorbing ability, much better than non-perforated plates. If the depth of the aperture is increased, the sound absorption of perforated plates will be increased lightly. Therefore, they use perforated jute panels in buildings and industrials as interior walls and ceilings. There is great potential for manufacturing soundproof equipment on ships, such as soundproofing in the engine room.

To possess many superior characteristics of tensile properties, compressive strength, flexural strength, interlaminar shear strength and impact strength, jute fiber reinforced epoxy composites are recognized for their potential use in engineering products (Shivamurthy et al., 2020). According to Asheesh Kumar (A. Kumar & Srivastava, 2017), they arranged an Epoxy piece and a Jute fiber-epoxy composite by using a manual lay-up technique. So they had to use an open type mold made of mild steel plate. Through the test, they realized the jute epoxy composite had increased tensile and compressive strength. Bundle strength of fibers and the number of fibers in a bundle are inversely proportional. Jute fiber reinforcement helps improve tensile and compressive strength.

Several researchers also paid attention to the enhancement of mechanical properties of jute fiber reinforced epoxy composites. With polyester and epoxy resin matrix, experiments by Gopinath et al. (Gopinath et al., 2014) have already shown that this method of fabricating jute fiber reinforced composites will have better mechanical properties than jute-polyester composites. Other tests by Boopalan et al. also discovered that the mechanical properties of raw jute and sisal fiber reinforced epoxy composites treated with sodium hydroxide produce better results than treated composites (Boopalan et al., 2012). With the purpose of comparing the jute fiber reinforced with both polyester and epoxy resins, Hariom Maurya et al. (Maurya et al., 2015) conducted some tests, and concluded that the jute reinforced epoxy composite had better mechanical properties than the jute polyester composite. Loan et al. (Doan et al., 2012), in their work on one study design, tried to access the potential replacement of glass fibers by natural jute fibers to produce a structural bonnet for an off-road vehicle (Buggy enclosures).

When studying the epoxy composites with three kinds of reinforcement by glass fiber, untreated jute fiber and alkali-treated jute fiber, the authors (Gassan & Bledzki, 1999) measured that the tensile properties of composites with untreated jute fiber reinforced epoxy fibers were inferior by 50 percent, whereas the ones using alkali-treated jute fibers exhibited only 30 percent reduced tensile properties than the same glass fiber reinforced epoxy composites. The conclusion is that alkali-treated jute fibers in making jute fiber reinforced epoxy composites is one of the best methods in order to increase the mechanical properties of such materials. Important ship structures such as the frame and shell can be fabricated with jute-reinforced composites as the mechanical properties of the material are improved.

4. Conclusion

Achieving marine applications such as fiberglass-reinforced composites requires further improvement of the mechanical properties of jute-reinforced composites. More and more new technologies and modern processing techniques are born, promising to produce jute fiber reinforced composite materials with mechanical properties equal to or superior to those of glass fiber reinforced composites. This material has great potential for application in the manufacture of ship parts and hulls. More research is needed in the future to improve the tensile strength, yield strength and other properties of jute fiber reinforced composites

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