Coir Fiber Reinforced Composites: A Review

Charles Chikwendu Okpala, Kenneth Somto Onukwuli, and Okechukwu Ezeanyim
Correspondence Address
Department of Industrial/Production Engineering,
Nnamdi Azikiwe University, P.M.B. 5025 Awka,
Anambra State, Nigeria.
Email: cc.okpala@unizik.edu.ng

***Abstract*—Polymer materials have gradually displaced other materials in most applications such as automobile, construction, marine, aerospace, biomedical, electronics, and many other manufacturing industries as a result of improved research and knowledge. Composites reinforced with fibers of synthetic or natural materials have become more prevalent as the market grows in demand for lightweight materials with high strength for specific applications. Fiber-reinforced polymer composites not only have a high strength-to-weight ratio, but they also have exceptional properties like flexural strength, stiffness, wear resistance, high durability, impact resistance, damping property, and corrosion resistance. The paper presents a comprehensive review of mechanical and chemical properties, treatment, and applications of coir fiber reinforced polymer composites. Recent works on coir fiber reinforcement composite were discussed extensively in the study. The article observed that the performance of coir fiber polymer composites is primarily determined by the properties of the polymer matrix, quantity of coir fiber, coir form (continuous and non-continuous), and production procedure. As a result, the properties of the polymer matrix, the forms of coir, and the manufacturing procedures utilized to make the composite materials must be examined to determine the best material characteristic for the desired application. Also, retting and coir fiber extraction were given a considerable review.**

Keywords—coconut, coir fiber, retting, polymer matrix, reinforced polymer composite, fiber reinforcement, natural fiber

1. Introduction

The traditional use of synthetic reinforced polymer composites in manufacturing and engineering applications is gradually declining due to their high cost and bad impact on the environment; unlike non synthetic fiber they emit carbon dioxide when incinerated. Research and application of natural fiber polymer composites are growing rapidly due to their renewability and diversified nature, low density, bio-degradability, low energy consumption, low cost, high specific property, and non-abrasive nature. The discovery that the specific mechanical properties of natural fibers can be compared to that of synthetic fiber has prompted researchers to explore the use of natural fiber polymer composites. Due to the low processing temperatures of polymer matrix composites, they are a lot easier to process than metal-matrix and ceramic-matrix composites. These polymer composites could either be a thermoset or a thermoplastic matrix. According to Wang et al (2011), although thermoset matrix-based composites are more popular, thermoplastic matrix-based composites are gaining much consideration recently due its lower production costs, high strength, low moisture content, no curing, reprocessing flexibility, and high-temperature resistance.

Natural fibers have been found to dramatically improve the properties of materials such as strength, stiffness, fracture toughness, thermal stability, electrical conductivity, and wear resistance when used as reinforcements, thereby making them highly suitable for application in diverse fields such as construction, automobile, biomedical, marine, and aerospace. (Ali and Andriyana, 2020).

Coir is a natural fiber made from the husk of coconut fruit. It is coarse, thick, and long-lasting fiber. Coconut is abundant in India, ranking second in the world after the Philippines. (Shandilya et al., 2016). The husk contains coir fiber as well as a corky tissue known as pith. The husk is made up of water, fibers, and small amounts of soluble solids, and it has a higher biodegradability than other natural fibers due to its high lignin content. Due to this lignin content, coir fiber is suitable for applications such as automobiles, biomedical, railway coaches, marine, and other applications requiring longevity. Coir is relatively water-resistant and resistant to saltwater and microbial deterioration and its recent research as a polymer matrix reinforcement has yielded good results (Kakou et al., 2015; Mohanty et al., 2005).

Because of its remarkable performance in a wide range of applications, coir fiber polymer composite materials are a promising alternative to other natural fiber polymer composites. Okpala, Chinwuko, and Ezeliora (2021), noted that some of the "benefits of coir fibers are low level of deterioration, low thermal conductivity, insect proof, good insulator, fungi resistant, low cost, stiffness, high strength, resistance to corrosion, lightweight, less negative impact on the environment, durability, as well as ease of processing."

Composites, according to Thodsaratpreeyakul et al., (2017), should not be regarded simply as a combination of two materials, but as a combination of two distinct materials. The individual mechanical and physical properties of the materials should be tested to determine how the material combination will improve the polymer matrix in terms of mechanical and physical properties.

(Harish et al., 2009), investigated coir composites' mechanical properties, they used the scanning electron micrographs of ruptured surfaces to compare the interfacial properties of coir/epoxy composites to that of the glass/epoxy composites. These findings indicate that for low-bearing thermoplastic composites, coir can be used as a reinforcing material.

Fibers are natural or synthetic hair-like materials that come in continuous filaments or discontinuous elongate sections comparable to thread (Vignesh S et al., 2019). Mineral fiber, Plant fiber, and Animal fiber are the classifications of natural fiber. Minerals having fibrous crystal habit are abundant in the Earth's crust, the most important is commercial fibers from the asbestos family; chrysotile, and five amphiboles (Di Giuseppe et al., 2019). After plant fibers, animal fibers are the most commonly used natural fibers. They are often made of proteins and can serve as possible reinforcements in composites (Sanjay et al., 2018).

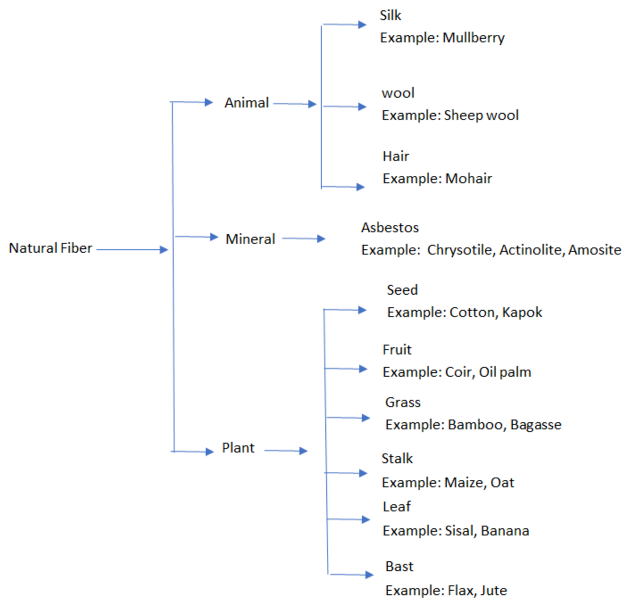

Figure 1: Classification of natural fibers

2. Coir Extraction and Treatment

Retting

Coir fiber is the thickest and most robust of all commercial natural fibers. It is a byproduct of the coconut industry, made from processed coconut husks that have been processed to remove their organic components. The coconut husk (exocarp) is composed of a fibrous zone (mesocarp) and a smooth water-repellent outer layer (epicarp). The mesocarp is made up of strands of coir fibro-vascular bundles that are embedded in non-fibrous parenchymatous connective tissue (Chand and Fahim, n.d.).

Figure 2: Cocoanut husks

Coconut retting, which can be in the form of dew or water retting, is moisture and biological process that dissolves or removes the coconut husk (exocarp), allowing the coir (mesocarp) fiber to be separated from the coconut. It is accomplished by immersing coconut husk in water for six to twelve months, during which the bonding components of the fibers and husk are dissolved. In dew retting, the harvested coconut is distributed equally across grassy fields, which is frequent in areas with limited water resources, where the combined action of bacteria, sun, air, and dew generates fermentation, dissolving much of the binding force of the exocarp and the mesocarp.

Coconuts' are submerged in water during water retting, which is the most extensively used method. Water that penetrates the exocarp part expands the interior cells, breaking the outermost layer and boosting moisture and decay-producing bacteria absorption. Dew-retted fiber has a deeper color and is of lower quality than water-retted fiber. The salinity of the water, nature of the husk, season, and depth of water are some of the factors affecting the retting process.

Retting occurs in two stages. The husk absorbs water and the plant tissues enlarge during the first or physical stage. Several components, such as carbohydrates, glucosides, tannins, nitrogen compounds, are dissolved in the tissue to form solutions. During the second stage, the biological stage, a range of microorganisms proliferate at the expense of the extracted compounds, so providing suitable environmental conditions and opening the way for the microorganisms to decompose the tissue binders. Fresh husks, utilized within a few days of husking nuts, are ideal for retting because they have good flexibility and color. Coir fibers that have not undergone the retting process are typically brittle and brownish, due to the oxidation of natural phenolic chemicals in the husk. The Retting procedure removes a considerable amount of the phenolic chemicals; coir fibers that have passed through the retting process are normally uncolored. The Retting process must be carefully monitored, under-retting makes separation difficult, while over-retting weakens the fiber.

Extraction

Large quantities of coir residue are produced during the coir fiber extraction process. Coir fiber is classified into two types: brown fiber from mature coconuts and finer white fiber from immature coconuts after soaking for a period of nine to ten months. To extract white fiber, properly retted husks are removed from the retting confinement, washed to remove any adhering slime, mud, or sand, and the exocarp is easily peeled off.

To separate the fibers, the husks are beaten on tree trunks or stones with wooden mallets. The fibers are cleaned, dried, and formed into stacks. The soaked husks are fed into breaker drums with spikes to extract the brittle fiber. To separate the long and short fibers, the drums are driven at high speeds in opposite directions. The brittle fibers that pass between the drums are collected and cleaned by passing them through another pair of drums with closer nails, after which the fibers are washed and dried.

Figure 3: Extracted coir fiber

(Pradeep and Dhas, 2015), studied the extraction of different fibers available from various parts of the palm tree. The palm fiber has a higher specific strength of 20% and its density is substantially lower when compared to that of glass fiber and carbon fiber. Higher tensile strength is found in the palm petiole more than in any other part of the palm tree. Better mechanical strength is ensured by the high cellulose content and low lignin content.

Coir Treatment

Before incorporating coir into the matrix, the coir must undergo surface treatment. Many studies on coir treatment have been conducted in the past to determine how it affects both the physical and chemical properties of the coir. (Rout et al., 2001), investigated the effect of coir treatment with 2% alkali on polyester composite, and the results revealed improved tensile strength and a reduction in strength above 2% of Sodium Hydroxide (NaOH) concentration. According to (Arrakhiz et al., 2012), the mechanical properties of the coir fiber can be improved by removing the lignin and hemicelluloses from wet alkali-treated coir polyester.

(Roy et al., 2012), investigated the shrinkage phenomenon, according to their results, 20% of alkaline-treated coir fibers have the greatest shrinkage and weight loss. This is because high NaOH concentrations absorb a large amount of water in the crystal structure, causing the fiber to swell. After the water was removed, structural shrinkage and weight losses were discovered. However, when compared to normal coir fibers, one alkaline pre-treatment on brown coir fibers produced poor results.

The effect of lignin content on composite properties was investigated by (Muensri et al., 2011), they observed that the removal of lignin does not affect mechanical properties, but it does reduce the samples' water absorption slightly. It was suggested that the remaining lignin content is still sufficient to cover the fiber surface, demonstrating that excess lignin content does not affect composite properties.

(Vilay et al., 2008), used bagasse fiber reinforced unsaturated polyester composites to study the effect of fiber loading and treatment of fiber surface properties. According to them, when compared to untreated fiber-based composites, treated fiber composites had higher tensile and flexural properties. The study showed that the addition of more fiber increases the tensile and flexural properties of bagasse fiber reinforced polyester composites.

The mechanical properties of coir fiber ethylene glycol dimethacrylate based composites were investigated by (Roy et al., 2012). They noted that under UV light, the surface of the coir fibers was modified with monomer Ethylene glycol DiMethAcrylate (EGDMA). The coir fiber's mechanical properties were significantly improved after being pre-treated with UV radiation. Alkali treatment of the fiber's surface was also performed using aqueous NaOH solutions (5–50 %) at varying temperatures and time. The Tensile Strength of the alkali-treated composites increased with increasing NaOH solutions (up to 10%) and then decreased. composites. Tensile Strength was increased further in composites made with alkali-treated fibers with EGDMA. The mechanical properties of coir fiber-based composites improved significantly after pre-treatment with mercerization and UV treatment.

The relationship between ash content and fiber treatment on the tensile behavior of coir reinforced polyester composite was studied by (Anyakora, n.d.), He used a hand lay-up technique to create composite panels from untreated and saline-treated coir reinforced with a polyester matrix. Surface treatment and manipulation of fiber content, as well as evaluation of ash content with tensile strength properties, were among the processing parameters. The results showed that increasing the fiber content and surface treatment of coir composite panels can improve their tensile strength and modulus of rigidity. The presence of higher ash content was revealed by Scanning Electron Microscopy (SEM) and Energy Dispersive Spectroscopy (EDS) analysis, indicating that the tensile strength of the treated coir reinforced polyester composite panels was improved positively. However, the toxic effects of acid on fiber were neutralized because of higher percentage of calcium in untreated coir.

3. Mechanical Properties of Coir

(Monteiro et al., 2008), investigated the mechanical properties of coir fiber polyester composites. They noted that the mechanical properties of coir fiber/polyester composites with ineffective coir fiber reinforcement are attributed to their low modulus of elasticity in comparison to bare polyester resin.

Mechanical properties of coir fiber reinforced epoxy composites using varied fiber length were studied by (Biswas et al., 2011), the result showed that increasing fiber length up to 20 mm decreases the hardness of coir fiber reinforced epoxy composites

The effect of lignin as a compatibilizer on the physical properties of coir fiber-polypropylene composites was investigated by (Bledzki et al., 2010), the study revealed that coir fiber polypropylene composites with lignin as a compatibilizer have better flexural properties than control composites. Tensile properties are not significantly improved because lignin is used as a compatibilizer.

Alkali treatment of palm fibers surface is effective for removing extractives and increasing crystallinity, roughness, and functional groups according to (Mulinari et al., 2016). The effects of fiber modification were evaluated using X-ray diffraction, morphology, and infrared spectra. The addition of fibers to an HDPE matrix increased tensile strength, modulus flexural, and strength. When compared to pure HDPE and natural fibers reinforced composites, the modified fibers reinforced composites had higher flexural modulus and tensile strength.

(Ahmad et al., 2011), investigated the effect of fiber length on the mechanical properties of cement-album composites reinforced with coir fiber. It was determined that increasing the fiber length increases the flexural strength, but incorporating long fiber into the cement reduced its workability by introducing voids, resulting in low density, increased water absorption, and water content.

The physical and chemical properties of some natural fibers are shown in figures I and 2,

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Table 1: Physical properties of various natural fibers. Source: (John and Anandjiwala, 2008)

Fiber	Tensile strength Mpa)	Young Modulus (GPa)	Elongation at break (%)	Density (g/cm^3)
Abaca	400	12	3 -10	1.50
Alfa	350	22	5.80	0.89
Bagasse	290	17	-	1.25
Bamboo	140 - 230	11-17	-	0.60 -1.10
Banana	500	12	5.90	1.35
Coir	**175**	**4-6**	**30**	**1.20**
Cotton	287- 597	3.30-12.60	7.8	1.50 -1.60
Curaua	500 -1150	11.80	3.70 - 4.30	1.40
Flax	345 -1035	27.60	2.70 - 3.20	1.50
Hemp	690	70	1.60	1.48
Henequen	500.70	13.20 ± 3.10	4.80 ± 1.10	1.20
Jute	393 - 773	26.50	1.50 – 1.80	1.30
Kenaf	930	53	1.60	-
Nettle	650	38	1.70	-
Oil palm	248	3.20	25	0.7 – 1.55
Piassava	134-143	1.07 – 4.59	21.90 – 7.80	1.40
Pineapple	144	400- 627	14.50	0.60 – 1.60
Ramie	560	24.50	2.50	150
Sisal	511 - 635	9.40 - 22	2.0 – 2.50	150

Table 2: Chemical Properties of various natural fiber

Name of fiber	Cellulose (w.%)	Hemicellulose (wt.%)	Lignin (wt.%)	Density (g/cm^2)	Reference
Banana	62 – 64	19	5	1-1.5	(Badrinath and Senthilvelan, 2014)
flax	71	18.6 – 21.6	2.2	1.4	(Li et al., 2007)
Bamboo	26 – 65	30	5 - 31	0.6-1.1	(Jayamani et al., 2014)
Sisal	78	25.7	12.1	1.33	(Nordin et al., 2013)
Jute	59-71.5	13.6 – 20.4	1.8 – 13	1.3-1.49	(Jayamani et al., 2014)
Kenaf	45 – 57	8 – 13	21.5	1.45	(Omrani et al., 2016)
Ramie	68.6 – 91	5 – 16.7	0.6 – 0.7	1.5	(Li et al., 2007)
Abaca	56 – 63	20 – 25	7 – 13	1.5	(Dittenber & Gangarao, 2012)
Hemp	57 – 77	14 – 22.4	3.7 – 13	1.48	(Li et al., 2007)
Alfa	45.4	38.5	14.9	0.81	(Dittenber & Gangarao, 2012)
Coir	**37**	**20**	**42**	**1.25**	(Omrani et al., 2016)
Betelnut	53.20	32.98	7.20	-	(Jayamani et al., 2014)
Curaua	70.7 – 73.6	9.9	7.5 – 11.1	1.4	(Dittenber & Gangarao, 2012)
Cotton	82.7 – 90	5.7	< 2	1.5-1.6	(Dittenber & Gangarao, 2012)
Palm	60 – 65	-	11 – 29	1.03	(Dittenber & Gangarao, 2012)
henequen	60 – 77.6	4 - 28	8 – 13.1	1.2	(Dittenber & Gangarao, 2012)
Piassava	28.6	25.8	45	1.4	(Dittenber & Gangarao, 2012)

4. Applications of Coir Fibers

Automotive Applications

Because of the remarkable growth in the demand for lightweight materials to increase fuel efficiency while reducing carbon emissions, the automotive industry is widely regarded as the industry in which the greatest volume of advanced composite materials could be used in the future. Natural fiber reinforcements are used in the manufacture of automobile body parts such as the engine hood, dashboards, and storage tanks.

(Ayrilmis et al., 2011), investigated coir fiber reinforced polypropylene composite panels for automotive interior applications. This study demonstrated that coir fiber is a viable candidate for use in the production of reinforced thermoplastic composites, particularly for partial replacement of high-cost and heavier glass fibers. The flexural and tensile strengths of the composites increased by 26% and 35% respectively, as the coir fiber content increased up to 60% wt. However, increasing the fiber content reduces the flexural and tensile strengths because the polymer matrix cannot cover all of the coir fiber's surfaces. Also, according to Holmes (2017), gaseous fuels such as hydrogen, as well as pressure vessels for natural gas, can be stored and efficiently transported using coir fiber composite.

(Alves et al., 2010; Koniuszewska and Kaczmar, 2016), studied the use of natural fibers to manufacture automotive parts. Impact stress and structural testing analysis were done to test their liability using the VARTM manufacturing method. The result showed that, the material's weight was reduced while its stability and strength were improved. Head impact criteria were used to measure the improvement in safety features, the studies pointed out that automobile body parts can be manufactured using natural fiber reinforced composites.

Civil Applications

In the last few decades, the construction industry has been looking for new materials and design processes to improve the mechanical, structural, and environmental performance of buildings and bridges around the world. Natural fiber polymer matrix composite has a potentially large market in construction applications, particularly in the construction of buildings, bridges, and housing, also lampposts, smokestacks, and highway culverts are some of the other applications. Reduction of overall system costs for erecting structures is the primary benefit of using polymer matrix composites in construction. Natural fiber polymer composite also helps in consolidation of fabrication operations, reduction in transportation and construction costs due to lighter weight structures, reduces maintenance cost, and increases the longevity of the structure because of the high corrosion resistance properties of coir fiber polymer reinforced composite.

According to (Gand et al., 2013), the use of traditional materials such as steel, cement and concrete have been in existence for ages, but they are insufficient in meeting certain mechanical and environmental requirements, necessitating the search for new materials that can meet these requirements. Even when subjected to the harsh environment of wet and dry cycling, fiber reinforced polymer composite bonded to the tension face of concrete beams exhibits an improved flexural strength and load-carrying capacity (Toutanji and Gómez, 1997). One of the shortcomings of these traditional materials is that cement production causes serious environmental concerns because one ton of cement production produces approximately one ton of carbon dioxide. According to (Sarde & Patil, 2019), when exposed to an alkaline or acid environment, the outer surface of cement deteriorates quickly.

Aerospace Applications

The aerospace industry is a major user of advanced composites. It is estimated that the aerospace industry consumes roughly half of all advanced composites production in the United States. Some of the factors driving the use of these materials in the aerospace industry are similar to those in the automotive industry: cost savings, weight reduction, and radiation shielding are top priorities in this industry. When compared to aluminum alloys, using FRP composites saves about 800 kg of weight in the A320 aircraft, while also finding increased percentage application in the A330, A340, and A380 superjumbo airliner (Oladele and Adewole, 2013). The B-787 Dreamliner is built with a large number of polymer composites and is intended to be a breakthrough in the aerospace industry (Koniuszewska and Kaczmar, 2016).

Marine Applications

Because of the excellent engineering properties that advanced composites provide, the marine industry has seen extensive use of them in recent decades. Fiber composites' moisture absorption properties are due to their structural or chemical composition, demonstrating a variety of applications in the marine environment (Dhakal et al., 2016). The major drivers that have led to an increase in the use of these materials for various marine sectors are weight and cost savings, as well as environmental sustainability (Peter, 2016; Shenoi et al., 2011).

Weight gain with respect to time can be used to monitor diffusion in the material structure. The number of water molecules absorbed is determined by the material's coefficient of diffusion. Though the coefficient of diffusion is lower in composite materials, it is affected by some factors, including the type of matrix material used, the type of reinforcement material used, and the manufacturing process used. (Kootsookos & Mouritz, 2004)pointed out that moisture absorption causes poor adhesion between the fiber and matrix in the composite structure, deteriorating the composite material's properties.

Military Applications

The military industry extensively makes use of nanotechnology in weaponry, communication, and protection. Over the years, there has been a tremendous increase in the use of nano-materials in the defense and military applications. To improve the performance of military devices while also increasing personnel comfort and survivability chances, poly matrix composites are efficiently used for making body armor, smart textiles, gloves, and boots. When reinforced with nano-materials such as Kevlar and graphene, polymer matrix helps to produce extraordinarily strong, smart, and lightweight high-technology battle suits.

(Natsa et al., 2015), used fiber reinforced polymer composite to develop military helmets. Various specimens were created in the study using various fiber formulations in epoxy resin. The physical properties of the produced helmet were measured and compared to those of other helmets. The produced helmet is lighter than both the Chinese and British helmets. It is only slightly heavier than a US Ballistic helmet. In casting the military helmet, he used 70% fiber content in 28% epoxy. They explained that an increase in the fiber content improves the hardness, tensile strength, and flexural strength of the helmet.

5. Conclusion

Natural fibers can be compared to synthetic fibers in terms of mechanical properties. It has an edge over synthetic fiber because of its availability, ease of production, and its environmental friendliness. Coir fiber is a better alternative when selecting natural fibers as polymer matrix reinforcement; this is due to its high lignin content that leads to low biodegradability which thus increases the longevity of its applications. Retting harms aquatic lives, therefore there is a need for alternative extraction techniques that will have similar qualities with coir fiber extracted through retting.

Coir exhibits different mechanical properties depending on the application and the type of polymer matrix, these mechanical properties can be influenced by coir treatment to suit the desired application. Polymer composites are one of the best developments in the manufacturing and construction industries and over the years it has proven to be indispensable. This research showed that coir fiber is an essential natural material for polymer matrix composites.

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