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Coconut Fibre (Coir) Composites: A Review

Francis Inegbedion[a*], Festus Inegbedion[b], Ifeoluwa Esther Osasona[c]

[a]Department of Production Engineering, Faculty of Engineering, University of Benin, Benin City, Edo State, Nigeria
[b]Department of Polymer Technology, School of Engineering Technology, Auchi Polytechnic, Auchi, Edo State, Nigeria
[c]Department of Production Engineering, Faculty of Engineering, University of Benin, Benin City, Edo State, Nigeria
Corresponding Author: francis.inegbedion@uniben.edu

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ABSTRACT

This article presents the versatility of coconut fibre and its technological application. One of the abundant natural fibres available in Nigeria, coir is derived from the shell of the coconut fruit. Growing concerns about global warming, forest depletion and oil reserves have prompted researchers to pay more attention to the use of natural fibre (coir) composites for power generation and other applications. The abundance of coconut in Nigeria has led to a greater focus on developing natural fibre composites for power generation and other uses. Coconut composites are receiving more attention from researchers and academics in the production of environmentally friendly, natural and sustainable engineering materials. Several researchers have studied the different uses of the coconut; a natural fibre that is abundantly available in Nigeria. This review article discusses the work that has been done by examining some of the uses and uses of coir. Various references to the properties, processing and application of coir composites have been cited in this overview. The research conducted and the conclusions drawn by various researchers over the past decades were briefly presented. The objective of this review is to highlight the potential of coir composites as an engineering material.

1. Introduction

Coir is found between the hard inner and outer shell of the coconut. The individual fibre cells are narrow and hollow, with thick cellulose walls, pale when immature, but become hard and yellow when a layer of flax is deposited on the walls during maturation. Each fibre cell is about 1 mm (0.04 inch) long and 10–20 m (0.0004–0.0008 inch) in diameter. The fibres are usually 10 to 30cm (4 to 12 inches) long. The two known types of coconut are brown and white. Brown coir harvested from fully ripe coconuts is thick, durable has high abrasion resistance and is mainly used for making mats, brushes and bags. Mature brown coconut fibres contain more lignin and less cellulose than fibres such as linen and cotton, so they are stronger but less flexible. White coconut fibres harvested from coconuts before ripening are white or light brown and are smoother, and finer, but weaker. They have generally spun yarn to make the yarn that is used in making mats or ropes. Coir is relatively waterproof and is one of the few natural fibres resistant to saltwater attack [1].

Coconut fibre, also known as coconut coir, is a tough, coarse fibre obtained from the coconut palm (Cocos nucifera). Coconut trees are grown in some parts of the world for their fruit, and the shell is usually discarded as waste. Although a mature coconut tree can produce 60 to 95 fruits per year, the mature fruits are separated from the hard husks, after which the fibres are obtained by rotting or separating them after soaking in water for a long time. The husk and peel of the tree are processed into natural fibres for reinforcing polymer composites [2]. Some of the benefits of coconut coir are low spoilage, low thermal conductivity, insect repellent, a good insulator, mildew resistance, low cost, stiffness, high strength, corrosion resistance, lightweight, less environmental impact, durability, and ease of use. In addition, coconut fibre absorbs less water than other natural fibres due to its reduced cellulose content [2].

The history of natural fibre-reinforced composite materials (such as coir) began in the last two decades. A time when there was great interest in using natural fibres to produce polymer composites. They are It is an environmentally friendly material and has been proven to be comparable to Fiberglass/polyester for strength and cost. Polyester composite combination reinforcement with natural fibres has proven to be an effective way to create materials suitable for different needs [3].

Natural fibre composites (coir) play a very important role in the production of environmentally friendly materials due to their high elastic modulus, high strength, and low carbon footprint. Coconuts (cocos nucifera) are widely cultivated in tropical countries for their fruit, and the shells and husks are usually discarded as waste. These parts of the coconut plant serve as a potential source of natural fibres used as composites [4]. This review will focus on the progress of coir as a material in the development of composites, an attempt to leverage renewable resources for the production of bio-composites. This report will also focus on the use of coir as reinforcement in matrix composite. The present study aims to help researchers appreciate the advantages of renewable resources for the development of composite materials using coir. The preparation and fabrication of various coir composites and the mechanical, structural and thermal properties of these composites have been studied by several researchers and are discussed in this review.

Preparation of Raw Materials. The collected coir fibres are usually torn into different sizes, either manually or by machine. The coir fibres are then either sun-dried or dried in a temperature-controlled oven (Figure 1). Briquettes can then be made after mixing with a suitable binder.

Figure 1: Coir Fibres

2. Literature Survey

According to Satyanarayana, et al. [5] coir was used to make upholstered furniture in addition to making mats, carpets, brushes and rope. They found that with the improved knowledge of coir's structural properties, it is possible to identify new uses for the fibre, such as Reinforcements in cement, rubber, clay and plastics.

Geethamma et al. [6] treated coir fibres using the caustic solution and their results showed improved properties when compared to untreated coir. They also looked at the dynamic mechanical analysis of short coconut fibre-reinforced NR composites. Their results show that coir fibres increase the modulus value.

Rozman et al. [7] concluded that coir packed with lignin-filled polypropylene composites has better flexural properties than control composites. This study investigates the use of polypropylene-reinforced coco-based natural fibre composites for automotive interior applications.

Rout et al. [8] explored the importance of coconut fibre-reinforced polyester composite surface therapy. Before being added with general-purpose polyester resin, coir washes alkaline therapy, whitening and vinyl grafting. Thanks to the surface treatment, the mechanical properties such as tensile, bending and impact resistance have been improved. The mixed composite fibre (65°C) showed improved flexural strength. Their results showed that the NaOH-treated fibre/polyester composite exhibited improved tensile strength.

Agopyan et al. [9] investigated the use of coir and sisal fibres as substitutes for asbestos in tiles. A total fibre volume fraction of 2% was used. The dimensions of the tiles were 487x 263x6mm (frame size) with a consumption of 12.5pcs/m2 and a size very similar to Roman ceramic tiles. A three-point bending specimen (span = 350mm, bending speed = 5mm/min) was used to determine the maximum load. The tiles were exposed in a rack facing north with an inclination of 30° and subjected to natural weathering under environmental conditions in a rural area in Pirassununga, State of Sao Paulo, Brazil (21° 59′ S) for a maximum of 16 and 60 months. The main long-term climatic conditions for the region were: average maximum temperature for January was 30.1°C, average minimum temperature for July was 9.5°C, average maximum relative humidity for January/February was 77%, relative humidity average minimum for August was 63% and average rainfall was 1363mm/year. After a curing period of 16 and 60 months, the maximum load on the coir tiles was 235 and 248N respectively, and on the sisal tiles respectively 237 and 159N. The main advantage of the reinforced tiles was higher energy absorption of at least 22% compared to unreinforced tiles, resulting in short-term cracking of the tiles during transport or installation.

Brahmakumar et al [10] in their research work demonstrated that coir can be used as an effective reinforcing material in the composite matrix. Their fibres were hybridized with a matrix to obtain better mechanical properties in a study on the mechanical properties of short fibre-reinforced polymer composites.

Geetamma et al. [11] investigated the influence of chemical modification, filler and fibre orientation in the production of coir-reinforced composites. In their study, the interfacial adhesion between coir and natural rubber (NR) was improved by treating the coir using an alkaline solution (sodium hydroxide and sodium carbonate). The composites containing 10mm long coconut fibres were cured at 150°C according to the respective cure times. They performed green strength measurements to measure the degree of orientation of the fibre.

Ramakrishna and Sandararajan [12] examined the variation in chemical composition and tensile strength of four natural fibres (coir, sisal, jute and hibiscus cannabis fibres), subjected to alternating wetting and drying and continuous immersion for 60 days in three different media (water, saturated lime and sodium hydroxide). The chemical composition of all fibres changed under the tested conditions (continuous immersion proved critical) and the fibres lost their strength. But coir fibres proved best at maintaining a good percentage of their original tensile strength under all conditions tested.

Bujang et al. [13] examined the dynamic properties of fibre-reinforced composites in their study. They have made composites containing up to 15% by volume of coir. Tensile tests of the obtained composites were carried out and an experimental analysis was carried out by them to determine the dynamic properties of the composite material produced. Their results showed that the modulus of elasticity varies with the fibre content of the composites. The stiffness coefficient decreased as the volume of the coconut fibre increased. However, they found that the attenuation peak increased due to the inclusion of the fibre. With a 10% higher fibre content, the attenuation peak results in a maximum value for almost all frequency modes. They also found that the effects of reinforcing the polyester matrix with coconut fibres make the composites more flexible and more easily deformed due to high stress levels and reduced high resonance amplitude. This suggests that hybrid composites have better resistance to water absorption. This work demonstrates the potential of natural fibre hybrid composites for use in a range of consumables.

Misra et al. [14] studied flame retardant coco-epoxy micro-composites. Coconut fibre was treated with saturated bromine water to improve electrical properties and then mixed with stannous chloride solution to improve flame retardant properties. It was observed that only 5% of the flame retardant filler reduced the density of smoke by 25% and the LOI value increased by 24%. The mechanical properties of the composites were hardly affected after the incorporation of fillers and their flexural strength and flexural modulus increased enormously.

Yuhazri and Dan [15] in their project used coconut fibre for the manufacture of motorcycle helmets. They used thermosetting polymer epoxy resins as matrix materials and coconut fibre as reinforcement. After developing the manufacturing process for the helmet shell, mechanical tests (dynamic penetration) were carried out on this composite material to determine its performance. The mechanical performance result showed that coir worked well as a suitable reinforcement for the epoxy resin matrix.

Almeida et al [16] investigated the mechanical and structural properties of coconut fibre-reinforced polyester composites. The resulting coir fibre was characterized by scanning electron microscopy combined with X-ray diffraction analysis. Composites are made in two compression moulds and coconut shapes up to 80% by weight. Randomly oriented polyester fibre composites are low-strength materials but can be designed to have a range of flexural strengths that allow them to be used as non-structural building elements. Young modulus of elasticity compared to pure polyester indicates that coir is not effectively reinforced. Rigid composites up to 50% by weight of fibres are obtained. At higher fibre quantities, the composites behaved as softer agglomerates.

Asasutjarit et al. [17] investigated the effect of pre-treatment on the properties of coconut fibre composites in their work. Composites are made from coir fibres that have been processed under various pre-treatment conditions. The conditions of use as well as the physico-mechanical and thermal properties of these composites are analysed. The surface properties of the untreated and treated coir were examined by scanning electron microscopy (SEM). The bond between the fibre and the matrix was shown to be improved with the pre-treated coir. SEM studies confirm that improved properties go hand in hand with better adhesion of the fibrous matrix.

Monteiro et al. [18] studied the mechanical performance of coco/polyester composites. The mechanical behaviour of coir/polyester composites, which eliminates the lack of effective coir reinforcement, is attributed to their low modulus of elasticity compared to pure coir-polyester resin. The study showed that the coir content can be increased by up to 80% and found that the composites stiffen up to 50% of the fibre filler and the composites look like agglomerates.

Yuhazri and Dan [19] developed a unique coconut fibre bulletproof vest that provides all the protection that a conventional vest can provide. They also noted that it's not only economical but also lighter. A normal bulletproof vest costs around 16,000 RM and weighs 9 kg, while this vest weighs only 3 kg and costs 2,000 RM. Tests have shown that the vest is capable of stopping 9mm bullets at a distance of 5m. The high-impact test was conducted on hybrid composite material using coir as reinforcement for ballistic armour and reported satisfactory results.

Charoenvaie et al. [20] reported in their research on studying the mechanical properties of green coir composites made with coir treated under different pre-treatment conditions. They discussed the changes in the relationship between the chemical composition and the morphological properties of coir under different coir pre-treatment conditions. They noted that the mechanical properties (modulus of rupture and internal bonding) of the composites increased due to changes in chemical composition and surface modification. Scanning electron microscopy (SEM) studies show that surface modifications improve fibre/matrix bonding.

Harish et al. [21] investigated the mechanical properties of coconut fibre composites in their research work. They developed coconut composites and studied their mechanical properties. Scanning electron micrographs obtained from fractured surfaces were used for a qualitative evaluation of the properties of the coconut/epoxy interface and compared to fibreglass epoxy. These results indicate that coir can be used as a potential reinforcement material to fabricate low-stress and low-absorption thermoplastic composites.

Mwasha et al [22] in their study investigated the time-dependent behaviour of reinforced banks built essentially on soft coconut fibre derived from coconuts, using a biodegradable geotextile as a reinforcing material. An analytical model of soil reinforcement, which takes into account changes in soil resistivity over time due to consolidation, was analyzed by using the GEO5 computer software to determine slope stability and the initial resistance required for the specified safety factor.

Rattanasom and Prasertsri [23] studied the relationship between mechanical properties, resistance to heat ageing, section growth behaviour and morphology in natural rubber. Results showed that percentage elongation at break and tensile strength decreased after thermal ageing while modulus increased with thermal ageing.

Rosa et al [24] studied the effect of fibre treatments on the mechanical properties of starch/ethylenevinyl alcohol copolymers/coir coconut biocomposites, studied the influence of fibre treatments by washing, mercerizing and bleaching and all treatments removed impurities surface on the fibres, allowing surface modifications and improvement of the thermal stability properties of both fibre-reinforced and fibre-reinforced composites. The results were supported by SEM analysis. Composites made from treated coir fibres had better tensile strength than those made from untreated fibres and improved tensile strength and elongation values compared to blends without fibres. Composites made with mercerized fibres showed a significant 33% improvement in tensile strength and a 75% improvement in tensile modulus compared to the pure starch/ ethylenevinyl alcohol copolymers/coir blend. Results indicate a better wettability of treated coir fibres with matrix and corroborated the role of treated coir fibre as not filler but as a reinforcing agent. This research indicated that starch/EVOH blends reinforced with treated coconut fibres have superior characteristics when compared to pure starch/ ethylenevinyl alcohol copolymers/coir blends.

Wang and Huang [25] used 2000 fibres randomly picked from a pile of coir fibres and analyzed the properties of the fibres to produce composite panels using a heat press with coir as reinforcement and rubber as a matrix. They studied the tensile strength of composites.

Carvalho et al. [26] investigated the effect of chemical modification on the effect of coir fibre composites. Green coconut lingo cellulose fibres were treated with an alkaline solution (NaOH 10% w / v) and then bleached with sodium chlorite and acetic acid. They mixed bleached alkali-treated fibres with impact-resistant polystyrene (HPIS) and placed them in an injection moulding chamber to obtain the tensile test sample. The samples were tested for tensile strength and the composite fracture surfaces were analyzed by scanning electron microscopy and X-ray diffraction. Experimental results showed that the addition of 30% of alkali-treated and bleached fibres reinforced in the HPIS matrix gave a significant change in mechanical properties compared to pure HPIS.

Júnior et al. [27] investigated the tensile properties of post-cured polyester matrix composites incorporating the finest coir fibres. Tensile samples containing up to 40% by volume of long aligned coir fibres were tested and their fracture surfaces were analysed using a scanning electron microscope. A relative improvement was found in the tensile properties.

Kindo [28] studied the development and characterization of a new set of natural fibre-based polymer composites consisting of coconut fibre as reinforcement and epoxy resin. Newly developed composite materials are characterized by their mechanical properties. Experiments were conducted to investigate the effects of the fibre length on the mechanical behaviour of these epoxy-based polymer composites. In the present work, coconut fibre composite materials are developed and their mechanical properties are evaluated. Their results showed that coir fibre can be used as a potential reinforcement material for many structural and non-structural applications.

Mahzan et al. [29] investigated the usefulness of coconut fibre-reinforced composites in sound-absorbing panels. Composite materials were constructed with the prescribed proportion of reinforcement and polyurethane as the resin. They used two microphone methods to study the acoustic properties of the material. Their result showed good acoustic properties of the composites and highlighted the potential of fibre-reinforced composites in sound absorption panels.

Abdullah et al. [30] studied the influence of the natural fibre content on the physical and mechanical properties as well as the fracture behaviour of coconut-reinforced cement. The mix design ratio was based on 1:1 for cement/sand and 0.55 for the water volume ratio. They used coconut fibre as reinforcement to replace the sand composition. Composites based on 3%, 6%, 9%, 12% and 15% wt., coir through the mixing and curing process were developed. They cured the composites in water for 7, 14 and 28 days. They reported that the 9% wt. coconut fibre-reinforced composite exhibited the highest fracture strength and compression modulus.

Aireddy and Mishra [31] investigated various formulations of coconut-reinforced epoxy matrix composites. They determined the abrasion resistance of composites in dry conditions using a disc spindle machine against 400μm grit sandpaper at a test speed of 0.540m/s and normal loads of 5, 10, 15, 20 and 25N. Their experimental results showed that the abrasion resistance of the composites depends on the concentration of coconut powder, the creep distance and the normal load applied. They observed that the abrasion resistance decreased with increasing normal load and increased with increasing coconut dust concentration.

Ayrilmis et al. [32] in their research on coir-reinforced polypropylene composite panels for automotive interior applications. This study showed that coconut fibre represents a potential reinforcement for thermoplastic composites, especially for the partial replacement of expensive and heavy glass fibres. They showed that coconut fibre is an essential element in the manufacture of thermoplastic composites, in particular, to effectively replace thick and relatively expensive glass fibres. When the amount of coir was increased to 60% by weight, the flexural and tensile properties of the composites improved by 26% and 35% respectively. They found that coir fibres, with the ability to greatly improve the dimensional stability of composites, can be used for non-structural applications, particularly in car door panels.

Hussein et al [33] examined the mechanical properties of green coir reinforced with HDPE polymer composite. They produced their samples according to Taguchi's L9 orthogonal lattice concept. The volume fraction of the fibre and the length of the fibre were considered as control parameters. An attempt was made to model the mechanical properties using the response surface methodology. The validity of the model was verified using the analysis of variance. The results indicated that the developed models are suitable for predicting the mechanical properties of the green coconut fibre-reinforced HDPE composite.

Jayabal and Natarajan [34] used the Taguchi method in the study of the mechanical and workability characteristics of coconut fibre. A tip diameter of 6mm, a spindle speed of 600rpm and a feed rate of 0-3 mm/rev gave the minimum thrust value; torque and tool wear in drill analysis. The short coir-reinforced composites exhibited tensile, flexural and impact strengths of 16.1709MPa, 29.2611MPa and 46.1740J/m, respectively. The regression equations were developed and optimized for studying the boron characteristics of coco-polyester composites using the Taguchi approach. A tip diameter of 6mm, a spindle speed of 600rpm and a feed rate of 0-3 mm/rev provided the minimum thrust, torque and tool wear in the drill analysis.

Jayabal et al. [35] studied the properties of hybrid coco-glass woven polyester composites. The composites were fabricated and their mechanical properties were evaluated for different staking orders. Scanning electron micrographs of fractured surfaces were used for a qualitative assessment of the interfacial properties of woven coco-glass hybrid polyester composites. These results demonstrated that hybrid coco-glass composites offer the advantages of both natural and synthetic fibres.

Jonjankiat et al. [36] studied the properties of environmentally friendly bio-composites based on polyvinyl alcohol (PVA) and cellulose microfibres (CMF). It has been noted that interactions of PVA -OH groups with CMP molecular chains lead to an increase in the melting temperature and crystallinity of bio-composites. It was observed that the addition of the CMF filler increased the shear strength of the specimens from 1.55 to 2.41MPa.

Mujahed et al. [37] performed experimental analysis on coconut fibre-reinforced composites. 4% of the coir was used to produce the composites, which are 40%, 50%, 60%, and 70% wet coir. They evaluated the dynamic properties of the composites. They observed the first five mode shapes of each coir fraction produced, which can be identified from 39.8Hz to 985Hz. From their results, the natural frequencies of 40% wet fibre were observed to be identified from the frequency 315Hz to 985Hz. Also, natural latex with 40% coco volume compared to 70% coco volume shows a slightly higher frequency only for the second to fifth mode frequencies. They however observed that, for the higher mode, the natural latex with 70% fibre volume has a higher value. Their results had shown that dynamic properties strongly depend on the fibre volume fraction. They concluded from their results that the sample containing 40% coir fibre has the highest value of the natural frequency, i.e. 315Hz to 985Hz compared to the other composition. They noticed that the increase in coir causes the composite to have low stiffness and ductility.

Tran et al. [38] in their paper, studied the effects of alkaline treatment on the interfacial and mechanical properties of biodegradable composites reinforced with coir. Their results showed that composites treated with alkali performed better than the untreated ones. In their experiments, fibres were soaked in a 5% NaOH solution for 48 hours to remove unwanted coconut kernel from the fibre and make the fibre capable of strengthening the fibre-gum bond.

Zuradia et al. [39] investigated the influence of fibre length on the mechanical properties of coco-reinforced cement-album composites. Experience has shown that increasing fibre length increases flexural strength. However, the incorporation of long fibres into cement paste reduced machinability, introducing voids leading to low density, but increased water absorption and water content. Their paper reports the development of a polymer matrix composite (epoxy resin) using coconut powder and eggshell powder in different volumes and evaluates its tensile strength, flexural properties and behaviour hydrophilic as well as the technical application of the resulting composites.

Dixit and Verma [40] studied the effect of hybridization on the mechanical properties of coconut fibre. The composites were fabricated using the compression moulding technique. The results showed that hybridization plays an important role in improving the mechanical properties of composites. The tensile and flexural properties of hybrid composites are significantly improved over non-hybrid composites.

Hu et al. [41] investigated the different weight ratios of coir fibres added to wood particles to produce hybrid boards. The two coir fibres used were randomized and randomly ruffled. The mechanical and sound absorption performances were evaluated. The experimental results show that the addition of coconut fibres improves the mechanical and acoustic absorption of the mechanical plates. The shape of a needle-like nonwoven was particularly effective in distributing the fibre evenly. Their sufficient strength and sound-absorbing material made them suitable for use in interior walls of automotive applications.

Karthikeyan and Balamurugan [42] in their study on the effect of alkali-treated coir on polyester composites experiment, different volume fractions were taken and their results showed that the volume fraction in the range of 10% to 30% showed optimal properties. The treated fibres showed better results than the untreated fibres. The flexural strength of these composites was lower than that of pure polyester.

Khan et al [43] investigated the mechanical properties of coconut fibre composite materials. The tensile strength, modulus of elasticity and elongation at break (%) of virgin coconut fibres were 152MPa, 5.3GPa and 36%, respectively. They treated the coir fibres using ultraviolet radiation and it was found that the mechanical properties improved significantly. Coconut fibre-reinforced composite based on ethylene glycol dimethacrylate was prepared and characterized by the authors. The surface of the coir was modified with ethylene glycol monomer under ultraviolet irradiation. Immersion time, ethylene glycol monomer concentration and radiation intensity were optimized to mechanical properties. They found the highest values of tensile strength, modulus of elasticity, elongation at break and polymer load at 50% by weight of ethylene glycol at the 125th step of ultraviolet irradiation for 7 minutes of immersion. Their research has shown that pre-treatment of coconut fibre with ultraviolet rays is effective in improving the mechanical properties of coconut fibre composites. They also treated the surface of the fibre with mercerized (alkaline treatment) using aqueous solutions of NaOH (5-50%) at different times and temperatures. They found out that the tensile strength of mercerized composites increased with increasing NaOH solution (up to 10%). They observed that composites made with mercerized fibres treated with ethylene glycol dimethacrylate showed a further increase in tensile strength. They concluded that pre-treatment with mercerization + ultraviolet treatment of the coconut fibre significantly improved the mechanical properties of coconut fibre composites.

Mir et al [44] characterized a single brown coir for the fabrication of polymer composites reinforced with characterized fibres. The adhesion between fibres and polymer is one of the factors affecting the strength of the manufactured composites. To increase adhesion, the coir was chemically treated separately with ($Cr_2(SO_4)_3 \cdot 12(H_2O)$) in one step and with ($CrSO_4$ and $NaHCO_3$) in two steps. Both raw and treated fibres were characterized by tensile testing, Fourier Transform Infrared (FTIR) spectroscopic analysis and scanning electron microscope analysis. The mechanical properties of the fibres characterized in this analysis were found to be better than the crude fibre and those of the doubly treated fibre even better. Scanning electron micrographs showed a rougher surface in the case of coarse coir. In the case of the treated coir, the surface was found to be clean and smooth.

Rao et al. [45] investigated the wear behaviour of coconut-filled, treated and untreated epoxy matrix composites. The effect of treated and untreated coir concentration (10%, 20% and 30%), variable loads (10, 20 and 30N) and variable speeds (300, 400 and 500) on the wear rate was analyzed. abrasive of the composite. The abrasive wear property of the composite is tested on a pen on a disc machine against 400m grit sandpaper. The Taguchi L9 method model was selected to minimize experimental times and investment costs. However, the treated fibre composite was found to exhibit better abrasion resistance than untreated fibre composites. The degree of abrasive wear decreases as the amount of coconut powder increases. As the load increases, the wear rate also increases.

Romli et al. [46] performed a factorial study on the tensile strength of epoxy composite reinforced with coco. Volume fraction, curing time and pressure load were used as parameters for the solidification of the composites. According to the results, the volume fraction influences the tensile strength of the bond.

Zulkifli et al. [47] in their article studied the acoustic properties of natural organic fibres (Kenaf and coconut) using the impedance tube method. They used Kenaf fibres as sound-absorbing fillers in the insulation panel and used coconut fibres as reinforcement in the perforated composite panel. They made the perforated plate with coir/polyester composites using coir volume fractions of 10%, 20% and 30%. They varied the perforation area of the perforated plate by 10%, 20% and 30%. While processing, the kenaf fibreboard was treated with PVA and cut into 100mm and 30mm diameter samples for low and high-frequency testing. They determined the density of coconut fibre to be 32.2g/cm3 while the density of kenaf fibre was 42.6g/cm3. Their results obtained showed that the optimum sound absorption coefficient index for kenaf fibre was 0.8 with a fibre volume fraction of 10% and the perforated coconut/polyester composite panel at 10% of the perforated areas.

Verma et al. [48] examined the use of coconut fibre, a natural fibre abundantly available in India and Africa, and explored the possibilities of coconut fibre polymer composites and their mechanical properties, as well as reinforcement in the matrix polymer. They noted its wide application, especially in packaging and furniture. Their study showed that fibre modification improves resistance to moisture-induced degradation of interfacial and composite properties.

Murali et al. [49] prepared briquettes from biomass residues such as coconut pulp, sawdust and sugarcane residues, sun-dried and pressed without binders. The results showed that the calorific values for coconut pulp, sawdust and sugar cane briquettes were 23.98, 20.37 and 18.89 MJ/kg respectively. They observed that the lowest ash content of the briquettes produced was 1.8% for sugar cane, while that of sawdust recorded the highest ash content value of 28.13%.

Natsa, et al. [50] successfully developed a military helmet with a coconut fibre-reinforced polymer matrix, they obtained a positive result after evaluating the mechanical properties of the manufactured helmet samples. However, they felt that the impact test, arguably the most important test of the study, showed a constant improvement as the coir was increased to 8,733N/mm2. They note that due to its remarkable flexural strength and toughness, coir has also been used as reinforcement in affordable concrete structures, mainly in earthquake-prone countries.

In their work, Obele et al [51] investigated the mechanical properties of coconut fibre-reinforced epoxy composites for the production of helmet shells. Samples were prepared using manual layering techniques and the mould was made from an existing helmet shell. Treating the coir with an alkaline solution removes wax, lignin, oils and other components from the fibre that can reduce the adhesion between the fibre and the matrix, resulting in a weak boundary layer. 30% by weight coir filler gave the maximum impact strength, the maximum load the composite can withstand. Above 50 wt% coir, there is a decrease in tensile strength due to poor circulation of the epoxy matrices around each other. They observed that the coco/epoxy tensile modulus increases with increasing stress.

Kong al. [52] used PVA embedded with NaOH-modified coconut fibre to form reinforced composites in their work, and results showed improved hardness and modulus properties with increasing fibre volume fraction. The samples were made by hot pressing. A high level of alkali-modified fibres is essential in composite manufacturing to produce composites with high modulus, high hardness, high degradation temperature, and low moisture sensitivity. The moisture absorption and release test confirmed that the moisture absorption and moisture release capacity of composites could be reduced by increasing the treated fibre content. The composite material having these properties can be used in biodegradable food packaging and other applications.

Wang et al. [53] investigated the weather resistance of various rubber-modified asphalts against ageing. Dynamic shear rheometer and dynamic mechanical analysis showed that chemical and rheological properties changed significantly with weathering.

Sotannde et al. [54] in their research work produced briquettes induced by molasses from coconut shells and bambara nuts. They subjected the briquettes produced to both physical and combustion tests. Tests showed that most changes in briquette properties were largely influenced by the type of biomass residues used, while molasses content also had a significant effect at $p<0.05$. They noted however that, the best blend of Bambara nut and coconut shell briquettes was produced when the molasses content was 30%. Conversely, the best coconut briquette was produced when the molasses content was 35%. They recommended these two steps to produce quality briquettes from these agricultural residues.

Bongarde and Khot [55] coir-reinforced polymer composites have been used for industrial and socio-economic applications such as automotive interiors, panels and roofs as building materials, storage tanks, packaging material, helmets and mailboxes, mirror housings, paperweights, projector covers and voltage stabilizer covers.

Nasif [56] explains that coir has a remarkable interest in the automotive industry because of its wear-resistant quality and high hardness (not fragile like glass fibre), good acoustic resistance, mothproof, non-toxic, resistant to bacterial and fungal degradation and not highly combustible. He pointed out that coir fibre can withstand heat and salt water, and is also more resistant to moisture compared to other natural fibres.

Noah et al. [57] in their study evaluated the combustible energy properties of briquettes made from Arundo donax, coir and a mixture of the two agricultural wastes, using cassava starch as a binder. The physical parameters assessed in their study were: moisture content and specific gravity, while combustion properties included: percentage ash content, percentage fixed carbon, percentage volatile matter, calorific value, and d-test value. They recommended making briquettes from Arundo donax and coconut fibre mixed in equal proportions to improve burning properties as they have low moisture content, low ash content, high calorific value, a high percentage of fixed carbon and the highest cooking efficiency.

Tun et al. [1] in their work prepared and characterized coconut husk (coir) briquettes with a mesh size of -20 and a cut size of 0.3 cm in length using potato starch as a binder. The physical properties (volatile content, ash content, moisture, solid carbon content, maximum density, emission density) and combustion properties (calorific value, ignition time, cooking efficiency, combustion rate, consumption, fuel specifications) of the briquettes were evaluated. Their results have shown that the physical and combustion properties of coconut husk briquettes are good biomass fuel and are more achievable than charcoal for firewood.

Sabo et al. [58] in their work coconut husks and corn cobs were used to make briquettes. They examined the combustion properties of various briquettes made with different binders. They observed that the highest caloric value of 24.04Kcal/kg was obtained with coconut shells using gum Arabic as a binder.

Tanko et al. [59] evaluated the properties of briquettes made from rice husk and coconut shell in different ratios based on their thermo-physical properties. The evaluated calorific values of the briquettes of rice husk and coconut shell were 16.51MJ/kg and 18.60MJ/kg, with densities of 1.50g/cm3 and 3.00g/cm3, respectively. Comparisons of their experimental and calculated calorific values of the briquettes (17 - 21MJ/kg) showed that they agreed with those of the American Standard of Testing Materials (ASTM) and those reported in the literature.

3. Application of Coir.

This study has shown that coir composites have huge applications such as in asbestos manufacturing, automobile interior panels, brushes, bulletproof vests, carpets, furniture, mats, military helmets, mirror housings, motorcycle helmets, packaging, roofs, ropes, sound-absorbing panels, etc. This study also demonstrated that coir composites have good dynamic mechanical properties, combustion properties and physical properties and that coir can be used as reinforcement for most composites.

4. Conclusion.

This review was conducted to investigate the potentials of coir composites and to investigate the properties (combustion, mechanical and physical) of coir composites. This review reported the use of coir as reinforcement in matrix composites. This review reported the various works that have been carried out by researchers on coconut fibre composites to allow researchers to explore the enormous potential in this field. This report has focused on providing knowledge on the various fields of application and uses of coir composites. It also provided information on the various properties of coir composites. From this overview, it can be concluded that coir has excellent properties that can enable its use as an engineering material. Coconut fibre has a wide range of applications and its use can be of great help in the field of waste management.

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