Mechanical Properties and Applications of Coir Fiber Reinforced Composites

Charles Chikwendu Okpala[1], Emmanuel Chuka Chinwuko[2], and Chukwuemeka Daniel Ezeliora[3]

[1-3]Department of Industrial/Production Engineering, Nnamdi Azikiwe University, P.M.B. 5025 Awka, Anambra State, Nigeria.

Abstract: Due to their remarkable features like low density, non-toxic, availability, bio-degradability, improved strength, reduction of CO_2 sustainability, environmental friendly, and corrosion resistant, natural fibers have continued to displace synthetic materials as fibers of choice in the production of composites. One of such natural fibers is coir fiber which is extracted from coconut husks. The paper first reviewed the different applications of coir fiber. Husks from harvested coconut trees were retted for twelve months, during which anaerobic fermentation took place on the husks, after which the fibers were extracted and treated. LY 556 epoxy resins (Diglycidyl ether of bisphenol-A) which has adequate adhesion and strength, alongside chemical resistance was selected as matrix, while HY 991 hardener was chosen as curing agent for the solidification of the matrix and coir fiber. Molds with 15mm length, 10mm width, and depth of 5mm were made, after which coir fiber reinforced composites were fabricated with hand lay-up technique and cured, before their mechanical properties were determined with a Hounsfield Monsanto model S/N8889 Tensometer. The conducted tensile test revealed that the tensile strength of the composite increases with the addition of coir fiber, as it reached a peak of 32MPa at 8 percentage weight of coir fiber. This shows that the addition of treated coir fiber increases the tensile strength of the composite. However, additional increase in coir fiber recorded a substantial decrease in the tensile strength of the composite. Flexural and impact strengths were also conducted on the composite specimens after which the study concluded that the addition of coir fiber increases the mechanical properties of the composite.

Keywords: composites, coconut, coir fiber, cellulose, epoxy resin, materials, tensile strength

1. Introduction

A composite refers to a material that comprise of two or more distinct constituents that when joined together are quite stronger than the individual components. Here, a stronger material that is known as reinforcement is embedded in a weaker one known as matrix, to form a new material with improved properties like rigidity, long term durability, and enhanced strength.

Also defined as a blend of two or more materials that leads to a new material with enhanced properties when compared to the separate components, the homogeneous matrix constituent is strengthened and reinforced with a stronger and hard component that is generally fibrous, but may also have a particulate or different shape.

According to Verma et al (2013), composites are achieved by the combination of two or more materials which results in a unique combination of properties, one of which is made up of stiff, long fibres and the other, a matrix or binder which holds the fibres in place. They pointed out that they "consist of one or more discrete phases embedded in a continuous phase to produce a multiphase material which possesses superior properties that are not obtainable with any of the constituent materials acting alone."

Fiber Reinforced Plastics (FRP) generally denote a thermosetting polyester binder or matrix that contain glass fibers, and are always sought after due to their enhanced qualities which include good mechanical properties, affordability, low density, versatility, proper thermal insulation, rigidity, decreased tool wear, and durability. However, in the recent times, manufacturers have fully embraced and preferred natural fibers over synthetic reinforced fibers, as natural fibers have demonstrated their better qualities in all spheres of engineering applications.

Ayrilmis et al (2011), observed that natural fibers also offer economic and environmental benefits over traditional inorganic reinforcements and fillers, and that as a result of the advantages, natural fiber reinforced thermoplastic composites are gaining popularity in applications like automotive and non-structural constructions. The good qualities, abundance, and affordability of natural fibers when compared to conventional synthetic fibers have made them materials of choice in reinforcements for polymers. The constituents of natural fibers are pectin, substances that are soluble in water, cellulose, lignin, hemicellulose, and wax.

Although the limitations of the applications of natural fibers as reinforcements include increased absorption of moisture and reduced impact strength, however its advantages which include bio-degradability, ease of extraction, sustainability, low density, weight reduction, high modulus, affordability, reasonable mechanical properties, and reduced tool wear during production, its benefits far out-weigh the disadvantages.

Some of the natural fibers that have been widely applied as reinforcements in composites include rice husks, straw, bamboo and sugar canes, glass reeds, water hyacinth, pennywort, plantain and banana pseudo stem, wood, flax, oats, hemp, papyrus, raphia, kapok, pineapple leaf, coconut (coir), palm tree fruit empty fruit bunch, sisal, rye, kenaf, among others.

Coconut fiber which is also known as coir fiber is a hard and coarse fiber that is acquired from coconut tree (cocos nucifera), the trees are cultivated expansively for its fruits in topical parts of the world, while the husks are generally been discarded as wastes. Although a fully grown coconut tree can have up to 60 to 95 fruits annually, the ripen fruits are separated from the hard shell in a process known as dehusking, after which the fibers are obtained by retting or separated after a prolonged soaking in water. The shells and husks from the tree are being processed as natural fibers for the reinforcement of polymer composites.

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. Also, because of their decreased cellulose content composition, coir fibers soak up water to a lower degree when contrasted with other natural fibers.

2. The Applications of Coir Fibers Reinforced Composites

Over the years, coir fiber reinforced composites have been widely applied in diverse areas due to their corrosion resistance and preferred mechanical properties. According to Bongarde and Khot (2019), coir fiber reinforced polymer composites have been “developed for industrial and socio-economic applications such as automotive interior, paneling and roofing as building materials, storage tank, packing material, helmets and postboxes, mirror casing, paper weights, projector cover, as well as voltage stabilizer cover”

Ayrilmis et al (2011), observed that the coir fiber is a potential material for manufacturing of reinforced thermoplastic composites that will possibly be a substitution for expensive and heavier glass fibers. They noted that with the ability to substantially enhance composites’ dimensional stability, that coir fibers can be adopted for non-structural applications especially in door panels of automobiles.

Nasif (2019), explained that “among the natural fibers, the coir fiber has remarkable interest in the automotive industry owing to its hard-wearing quality and high hardness (not fragile like glass fiber), good acoustic resistance, moth-proof, not toxic, resistant to microbial and fungi degradation, and not easily combustible.” He pointed out that coir fibers withstand heat and salt water and also offer better resistant to moisture when compared to other natural fibers.

Natsa, Akindapo, and Garba (2015), successfully developed a military helmet using coconut fiber reinforced polymer matrix, they achieved a favourable result after the evaluation of the mechanical properties of the produced helmet samples. However, they opined that the impact test, which unarguably is the most crucial test of the study, revealed a constant improvement as the coir fiber is increased to $8.733 N/mm^2$.

Coir fibers have also been applied as reinforcement in affordable concrete structures mainly in earthquake prone nations due to their remarkable flexural strength and toughness. According to Satyanarayana, Kulkarni, and Rohatgi (1981), apart from the production of mats, carpets, brushes, and ropes, coir fiber is used in the manufacturing of upholstery. They noted that with the enhanced knowledge of the structure-property nature of coir fiber, that it is feasible to identify novel applications of the fiber like reinforcements in cement, rubber, clay, as well as plastics.

According to Santos da Luz et al (2017), epoxy composites attained the required standard for ballistic protection in counter of increased power of 7.62 ammunition when combined with diverse fractions of coir fiber.

Coir fiber reinforced composites have been widely applied in electronic components, automotive parts, sporting equipment, rehabilitation and construction of roads, household appliances, helmets, wears, structures, aeroplanes, trains, as well as in numerous other applications.

3. Coir Fiber Extraction

The durability of coir fibers when compared to other natural fibers can be ascribed to its increased lignin content which makes it quite appropriate for use especially where gradual bio-degradability is needed. The two types of coconut fibers are white fibers which are extracted from unripe coconuts (from six months) and brown fibers extracted from mature and ripe coconuts that are up to one year.

The structure of coconut which includes the coir is depicted in figure 1.

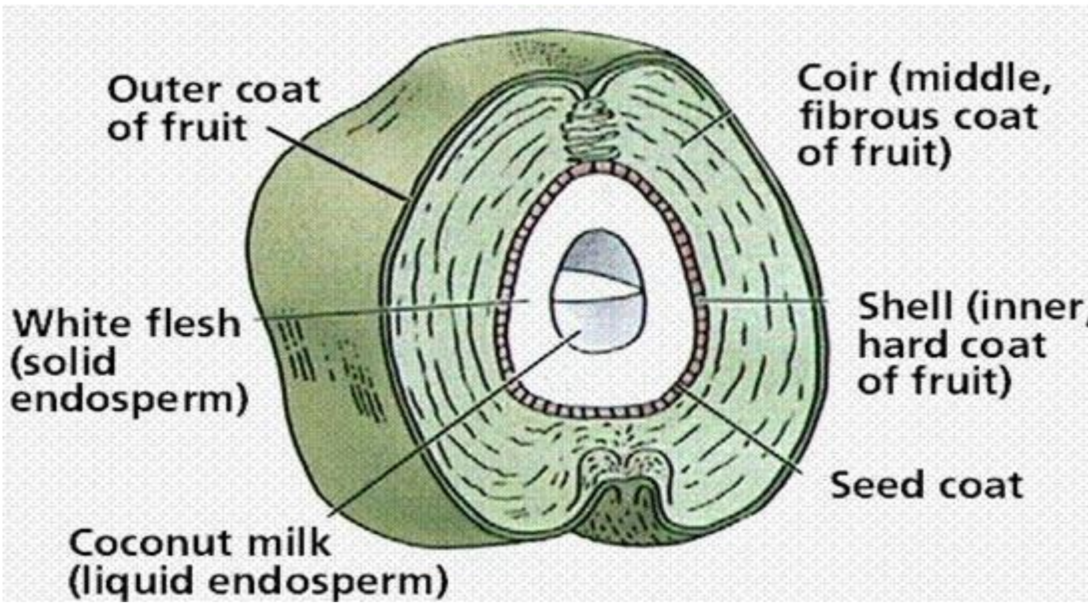

Figure 1: The structure of coconut

Omoniyi and Ayodele (2020), observed that the production of natural fiber reinforced composite materials entails proper processing of fibers into the required dimensions, and then introducing the matrix to form composites. They explained that of the numerous available natural fibers, that coir fiber is one of the toughest, as it attracts a lot of difficulty in separating or reducing its size for natural fiber composite production.

Coconut husks with embedded coir fibers are shown in figure 2.

Figure 2: Coconut husks with un-extracted coir fibers

The traditional process of coir fiber extraction is quite time consuming and tedious as the husks of the harvested coconuts obtained from coconut trees in Eziora village, Adazi-ani in Aniocha Local Government of Anambra State – Nigeria, were soaked in water for twelve months, during which anaerobic fermentation took place on the husks, thereby enabling them to separate after softening.

To successfully separate the fibers as shown in figure 3, mallets were used to beat the husks on hard surfaces, after which the freed fibers were thoroughly washed and dried under the sun.

Figure 3: Extracted coir fiber

Hasan et al (2021), noted that when compared with other natural fibers like jute, coir fibers require longer period of up to 12 months for biological retting processes. They pointed out that the perfect retted coconut husks are later detached from other poorly retted husks and washed with water to remove impurities like mud, sand, and slime from the surface.

Although the traditional extraction process which involves retting over a long period yields the best white fiber quality which are employed for diverse usage, in the mechanical fiber extraction processes the husks are immersed for just five days in tanks of water after which decorticating or de-fibering machines are used to extract the fibers.

Commenting on the mechanical processes of coir fiber extraction, Coir Board (2018), explained that crushing the husk in a breaker of decorticating machine opens the fibres, and that by using revolving “drums” the coarse long fibres are separated from the short woody parts and the pith, after which the stronger fibres are washed, cleaned, dried, hackled and then combed.

4. Materials and Methods

a. Preparation of Coir Specimen

The traditionally extracted coir fibers from the coconut husks devoid of any chemical treatment were natural and raw. To achieve the desired quality, the fibers were thoroughly washed in clean running water, after which they were oven-dried at 38 Degrees Centigrade for 14 hours, before they were subjected to diverse treatments.

The extraction and treatment process of the fibers is depicted in figure 4.

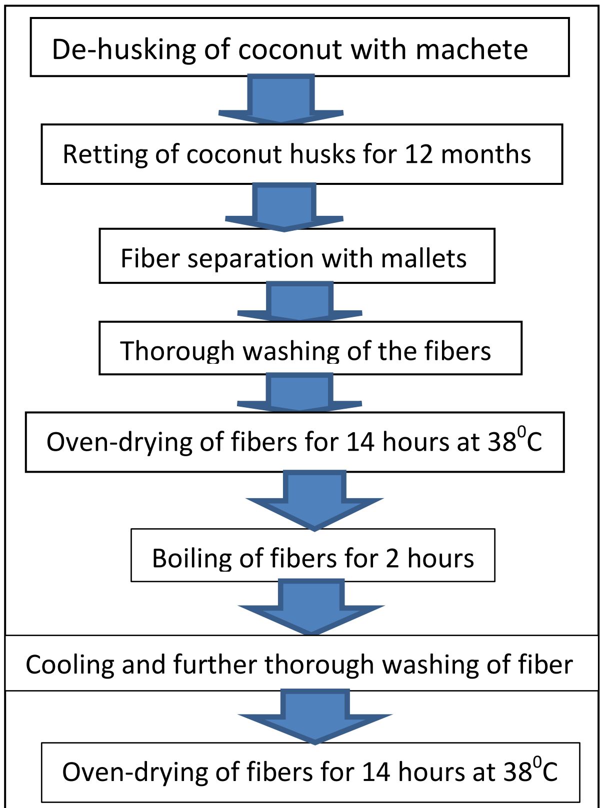

Figure 4: Fiber extraction and treatment process

After the oven-drying, the coir fibers were cut into smaller pieces of 9mm length known as whiskers with a cutting machine.

b. Chemical Properties

According to Hassan et al (2021), the three main chemical constituents of plant-based fibers are cellulose, hemicelluloses, and lignin, and that where the cellulose and hemicelluloses are polysaccharides, lignin is a three-dimensional amorphous polyphenolic macromolecule, which entail three different types of phenylypropane units. They noted that celluloses which are the main strength of natural fibers are crystalline, whereas lignin which is usually positioned at the surface of fibers is amorphous.

Apart from lignin, cellulose, and hemicellulose, other chemical compositions of coir fiber are water soluble, pectin, and ash. As depicted in figure 5, the coir fiber contains 42.1% of lignin, 35.3% of cellulose, 6.2% of hemicellulose, 9.3% water soluble, 4.1% pectin, and 3.0% ash.

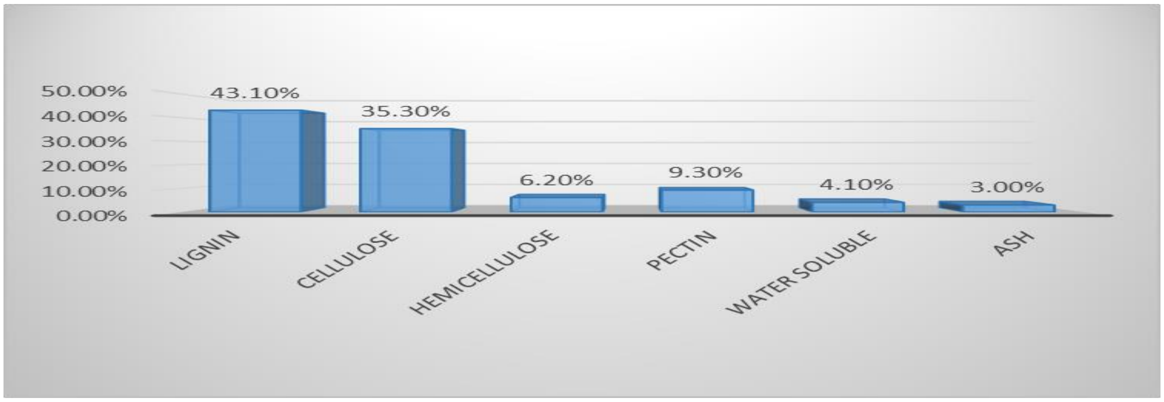

Figure 5: Chemical properties of Coir Fiber

The high lignin content of coir fiber enhances its strength and rigidity, thereby making it one of the most preferred fibers for diverse applications.

c. Physical/Mechanical Properties

Density, modulus of elasticity, strength, and also elongation at break are the major physical properties of coir fibers. As shown in table 1, the extracted coir fiber has a density of 1.24 g/cm^3, strength of 139Mpa, modulus of elasticity of 6.4GPa, 28% of elongation at break, and water absorption saturation of 132%.

Table 1: Physical/Mechanical of properties of the extracted coir fiber

Physical/Mechanical Properties	Content
Density	1.24 g/cm^3
Tensile Strength	139Mpa
Elastic Modulus	6.4GPa
Elongation at Break	28%
Water Absorption Saturation	132%

d. Epoxy Resin and Hardener

Also known as poly-epoxides, LY 556 epoxy resins (Diglycidyl ether of bisphenol-A) which has adequate adhesion and strength, alongside chemical resistance and desired mechanical properties was selected as matrix, while HY 991 hardener was chosen as curing agent for the solidification of the matrix and coir fiber.

The epoxy resin and hardener are shown in figure 6.

Figure 6: Epoxy resins and hardener

To ensure adequate safety, the handling of the epoxy resins and hardener were performed with gloves and face shield in properly ventilated shop floor, in order in order to avoid skin blisters and other negative dermatological effects.

e. Molds Preparation

Wooden rectangular molds with 15mm length, 10mm width, and depth of 5mm were made from stable planks that were smoothened with sand paper.

f. Preparation of Composites

The hand lay-up technique was used for the composite preparation. It entails placing different layers of the dry coir fibers and using a brush to manually apply the thoroughly mixed epoxy LY 556 and HY 991 hardener in 8:1 ratio by weight on the reinforcing coir fiber. Continuous prolonged stirring was undertaken in order to release entrapped bubbles of air. The process was repeated with different weight percent of coir fibers with respect to epoxy matrix as follows: A(2wt%), B(4wt%), C(6wt%), D(8wt%), and E(10wt%).

To enhance seamless retrieval of the composite after fabrication, silicon was sprayed on the mold before the mixture was poured into the different molds, after which bricks of 8.5kg each was placed on top of the molds for the release of trapped air bubbles. Curing which is a very important aspect of manufacturing of composite materials was allowed to take place for 36 hours in atmospheric temperature of about 22 degrees centigrade, after which the composites were retrieved from the molds.

5. Results and Discussion

a. Tensile Test

For the determination of physical properties of composites such as toughness, strength, ductility, as well as Young modulus, tensile testing is the most versatile mechanical testing. The application of constant strain on the five different specimens of the composites with diverse weight percentage following the ASTM D-638 was conducted on a Hounsfield (Monsanto) Tensometer (Universal Testing Machine) depicted in figure 7, with a strain speed of 5mm per minute.

Figure 7: Hounsfield Monsanto Tensometer (Model no: S/N 8889)

As shown in figure 8, the conducted tensile test revealed that the tensile strength of the composite increases with the addition of coir fiber, as it reached a peak of 32MPa at 8 percentage weight of coir fiber. This shows that the addition of treated coir fiber increases the tensile strength of the composite.

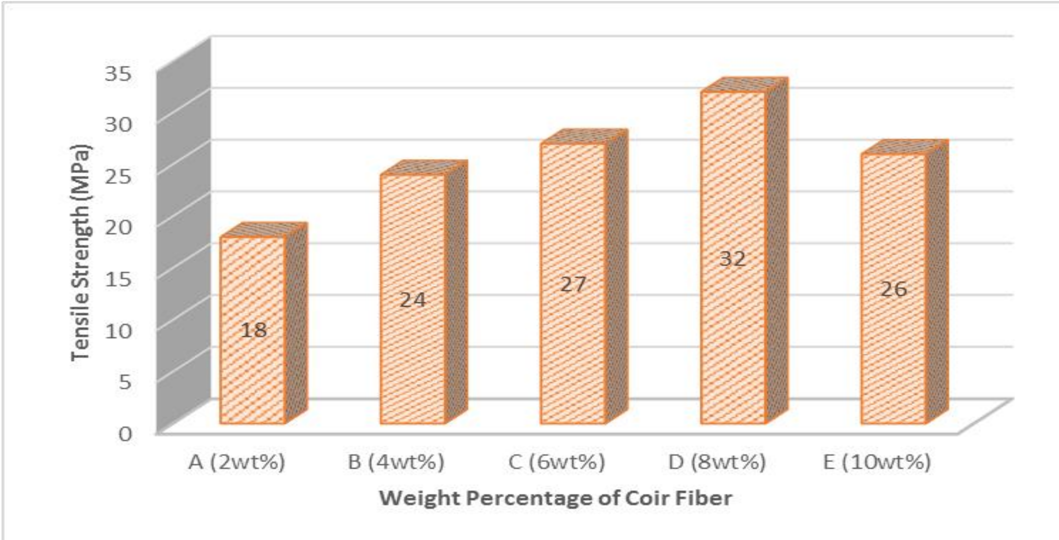

Figure 8: Tensile Strength at diverse coir fiber weight percentage

However, additional increase in coir fiber recorded a substantial decrease in the tensile strength of the composite. This also reveals that an increase of up to 10 and above percentage weight of coir fiber decreases the composite's tensile strength as the increase reduces the bonding force between the resin and matrix. According to Pani and Mishra (2019), maximum tensile strength obtained by coir reinforced epoxy polymer composite decreases after 10wt% increase in percentage of coir addition, because with lower percentage of coir there is better wetting of its particles by the epoxy matrix.

The Young's Modulus of the composites which exhibited a similar trend with the tensile strength is shown in figure 9.

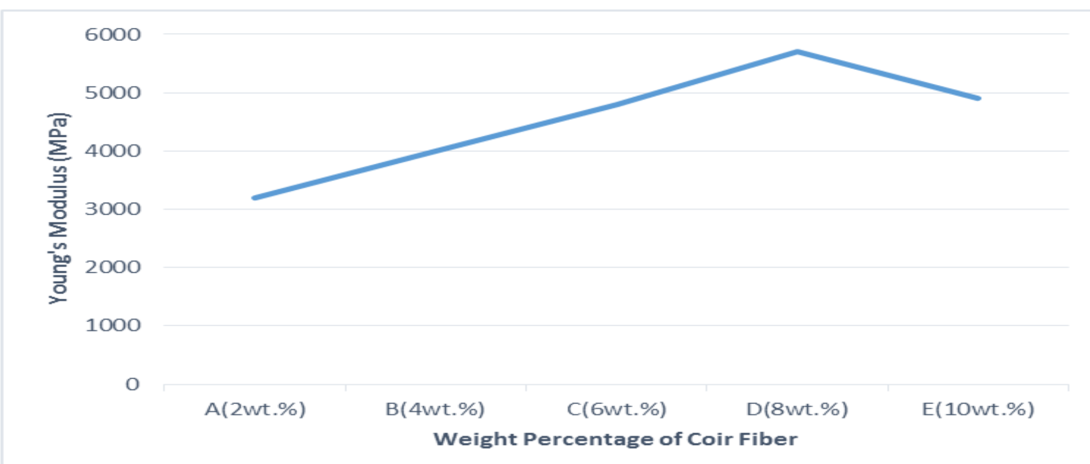

Figure 9: Young's Modulus of the composites at diverse coir fiber weight percentage

b. Flexural Test

ASTM D790 was used to prepare the 5 specimens for the flexural test. The test was conducted gradually until 5 percent deflection was achieved at slow speed.

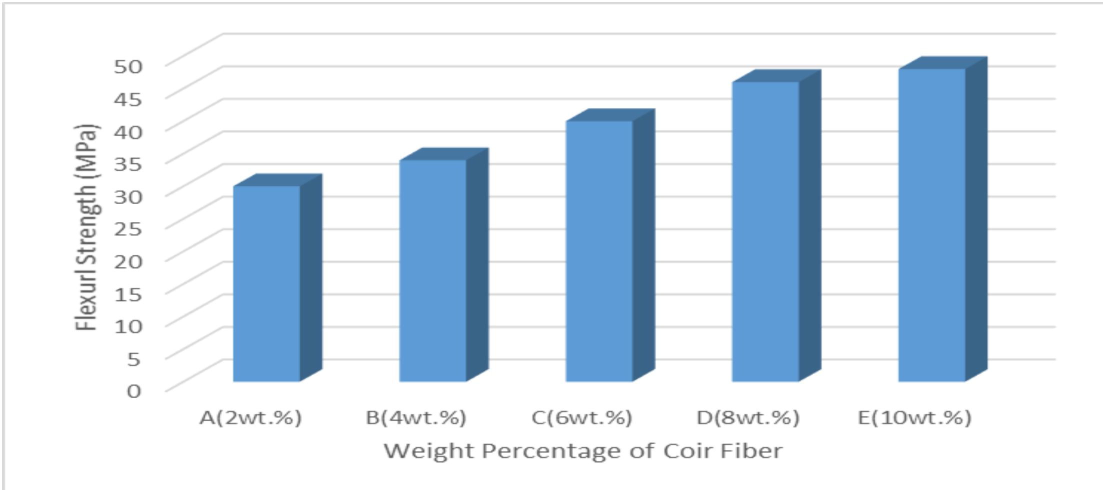

Figure 10: Flexural Strength of the composites at diverse coir fiber weight percentage

As shown in figure 10, the flexural strength of the composites recorded a steady increase from 30MPA at 2wt.% to 48MPa at 10wt.%, thereby indicating that the flexural strength of coir fiber reinforced composites increases with the addition of coir fiber up to 10wt.%. The result corroborates the findings of Obele and Ishidi (2015), who observed that the flexural strength of coir/epoxy composite reduces when the filler loading exceeds 10wt.%, due to a decrease in the composites capacity to withstand deformation under load at the increase of the filler loading.

c. Impact Test

Also referred to as Charpy test, which is a measure of a material's ability to withstand fracture failure under a rapid applied force at increased velocity, the impact test was undertaken in line with the ASTM D-256 in order to ascertain the specimen's toughness with a 2mm/min strain rate over a specified length.

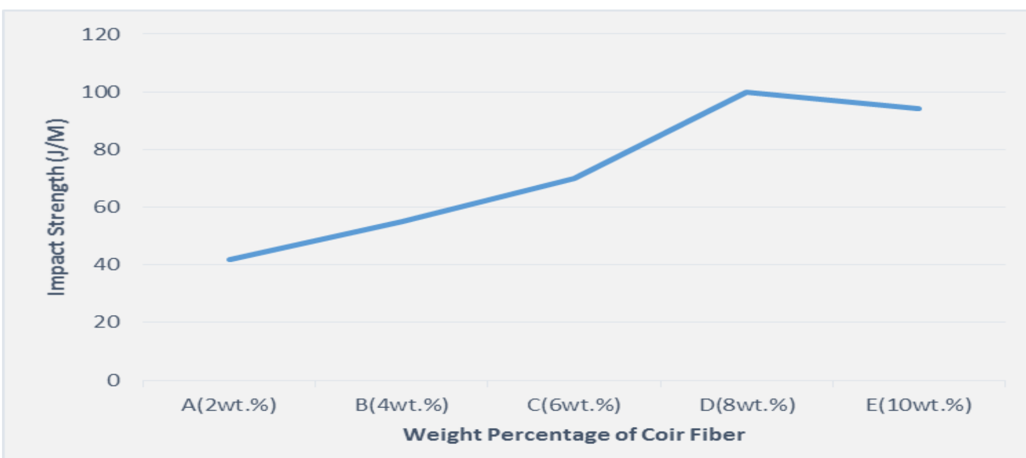

Figure 11: The Tensile strength of the composites at diverse coir fiber weight percentage

Figure 11 reveals that there is a steady increase in impact strength of the coir fiber reinforced epoxy composite from 42 J/M at 2wt.% up to the maximum of 100J/M at 8wt.%, before reduction. The increase can be attributed to increased composites compactness attained at the additional increase in coir fiber up to 8wt.%.

6. Conclusions

The study revealed the reinforcement of coir fiber to epoxy resin. The increase in percentage weight of coir fiber reinforcement is at its best at tensile strength of 32MPa, young modulus 5800MPa, and impact strength 100J/M, with percentage weight of eight 8%. An increase of up to ten percent weight (10wt.%) and above of coir fiber decreases the composite's tensile strength, young modulus and impact strength as the increase reduces the bonding force between the resin and matrix.

However, the increase in percentage weight of coir fiber, increases the flexural strength of the composite materials up to ten percent weight (10wt.%). In conclusion, the result shows that the reinforcement of coir fiber to epoxy resin mostly improve the composites mechanical properties.

References

1. Ayrilmis, N., Jarusombuti, S., Fueangvivat, V., Bauchongkol, P., and White, R. (2011), "Coir Fiber Reinforced Polypropylene Composite Panel forAutomotive Interior Applications" Journal of Fibers and Polymers, vol. 12, iss. 7
2. Bongarde, U., and Khot, B. (2019), "A Review on Coir Fiber Reinforced Polymer Composite" International Research Journal of Engineering and Technology, vol. 6, iss. 4
3. Coir Board (2018), "Coir Processing – Technology and Machinery" [Online]. Accessed from http://coirboard.gov.in/?page id=64 on 19 May 2021.
4. Hasan, K., Horvath, P., Bak, M., and Alpar, T. (2021), "A State-of-the-art Review on Coir Fiber-Reinforced Biocomposites" The Royal Society of Chemistry Journal, 2021, 11
5. Nasif, R. (2019), "Effect of Coir Fiber Length and Content on Mechanical Properties of Unsaturated Polyester Composites" Iraqi Journal of Applied Physics, vol. 11, iss. 3
6. Natsa, S., Akindapo, J., and Garba, D. (2015), "Development of a Military Helmet Using Coconut Fiber Reinforced Polymer Matrix Composite" European Journal of ngineering and Technology, vol. 3, iss. 7
7. Obele, C. and Ishidi, E. (2015), "Mechanical Properties of Coir Fiber Reinforced Epoxy Resin
8. Composites for Helmet Shell" Industrial Engineering Letters, vol. 5, iss. 7
9. Omoniyi, T. and Ayodele, E. (2020), "Development of a Coir Fibre Extracting Machine" International Research Journal of Engineering and Technology, vol. 7, iss. 7
10. Pani, D. and Mishra P. (2019), "Analysis of Mechanical Properties of Coir Composites with Varied Compositions" International Journal of Material Sciences and Technology, vol. 9, iss. 1
11. Santos da Luz, F., Monteiro, S., Lima, E., and Junior, E. (2017), "Ballistic Application of Coir Fiber Reinforced Epoxy Composite in Multilayered Armor" [Online]. Accessed from https://www.scielo.br/j/mr/a/vmnkdQBN6Skzpg7Q7t7kdzg/?lang=en on 14 June, 2021.
12. Satyanarayana, K., Kulkarni, A., and Rohatgi, P. (1981), "Structure and Properties of Coir Fibres" Proceedings of Indian Academy of Science (Engg.Sci.) Vol. 4, pt. 4
13. Verma, D., Gope, P., Shandilya, A., Gupta, A., and Maheshwari, M. (2013), "Coir Fibre Reinforcement and Application in Polymer Composites: A Review" Journal of Material and Environment Science, vol. 4, iss. 2