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EFFECTS OF NaOH TREATMENT AND FIBER CONTENT ON THE PHYSICAL AND MECHANICAL PROPERTIES OF COCONUT FIBER REINFORCED POLYSTYRENE FOAM COMPOSITES

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ABSTRACT

The purpose of this study was to determine how coconut fiber content after treatment with NaOH affects the physical and mechanical properties of treated coconut fiber (TCF) reinforced polystyrene foam (PSF) matrix composites. The coconut

INTRODUCTION

The world's population is quickly expanding, and human needs are also increasing in relation to population density (Tong and Qiu, 2020). The land area, on the other hand, does not expand in proportion to the increase in population density and urbanisation. As a result, horizontal building is challenging. Therefore, people must resort to vertical development, such as multi-story buildings or flats, to meet their needs. Professionals tend to

fiber was treated with 20% sodium hydroxide before being used as reinforcement in the PSF. The treated coconut fiber and polystyrene foam loadings ranged from 0 to 50 weight percent (wt%) of coconut fiber and 100 to 50 weight percent of polystyrene foam, respectively. The key findings of this study demonstrated that as the coconut fiber content increases, the physical properties of the composites, such as density, water absorption, and hardness, increase linearly. With an increase in fiber content of up to 20 wt% TCF, the mechanical properties of the composites, such as tensile strength, compressive strength, modulus of elasticity, and flexural strength, improve. So also, with an increase in fiber content, the percentage elongation at break of composites produced decreased. Composites containing 20 wt% treated coconut fiber had better fiber/matrix adhesion as well as improved physical and mechanical properties, making coconut fiber reinforced polystyrene foam composites suitable for built-up and engineering applications.

Keywords: Composites, Coconut fiber, Fiber content, polystyrene foam, Mechanical properties.

use a variety of techniques to develop lightweight construction materials in this situation (Dharmaratne et al., 2021).

The weight of the total apartment is exactly proportional to the dead load accumulated by walling materials such as bricks and blocks. As a result, the construction project's capital cost rises as well. On the other hand, the use of lightweight composite materials for the walls in high-rise buildings would dramatically reduce the dead weight that comes from solid walls. In this regard, lightweight composite wall panels have been identified as one of the most effective ways to address this issue (Das, 2012). Coconut fiber is one of the materials utilised to make such composites, and it is one of those materials. According to Putra et al. (2020) and Syed et al. (2020), coconut fiber has a considerable impact. The most well-known fibrous byproduct of coconut production is coconut fiber (coir). Coconut is abundant in tropical countries' coastal areas, and the globe produces at least 30 million tonnes of it every year. The husk of a coconut is made up of 30% fiber and 70% pith, with a high lignin and phenolic content. Coconut fiber is very elastic, durable, and rot-resistant due to its high lignin content. The high lignin concentration in coir fiber makes it tough, strong, and long-lasting. There are two forms of it: "bristle" fiber (combed, 20 – 40 cm long) and "mattress" fiber (random fibers, 2 – 10 cm long). The fiber is used in the filter pads of household furnaces and ventilation systems. In natural filters, it's frequently blended with hog hair (Dharmaratne et al., 2021).

Coconut fiber, for example, has a hydrophilic character. Furthermore, dirt and other contaminants on the surface of natural fibers might influence the fibers' bonding strength with the matrix. As a result, numerous studies have been conducted in order to improve the surface of natural fibers in order to improve the bonding strength between natural fibers and the matrix. Coconut fiber is an excellent choice for use as a filler in composites since it is strong, lightweight, heat resistant, saltwater resistant, inexpensive, and easy to procure (Sen & Reddy, 2011; and Arsyad et al., 2015).

Natural fibers have been treated in a variety of ways/methods to improve their compatibility. The treatment tries to change the fiber surface both physically and chemically. Chemical treatment is one way of increasing natural fiber qualities such as surface shape, dirt removal, fiber strength, and fiber-matrix interaction (Arsyad et al., 2015). Alkali treatment is a common chemical treatment for natural fibers. The majority of hemicelluloses, lignin, waxes, and oils soluble in alkali are expected to be removed causing the fiber surface to become rough due to reduced fiber aggregation (Carvalho et al., 2010).

Many studies have been conducted on the alkali treatment of coconut fiber (Karthikeyan & Balamurugan, 2012; and Karthikeyan et al., 2013). The fatigue life of a large stress composite reinforced with coconut fiber treated with sodium hydroxide was shorter (Mulinari et al., 2011). In general, treated natural fiber composites have a higher tensile strength and modulus of elasticity than natural fiber composites that have not been treated (Arsyad et al., 2015).

As a result, the goal of this research is to see how NaOH treatment affects the loading of treated coconut fiber into reinforced polystyrene foam composites. Its applicability will add to the list of renewable and sustainable bio-fibers, and it might be used to replace other fibers. Because the hydrophilic fiber and hydrophobic matrix are incompatible, treating coconut fiber chemically with sodium hydroxide is a novel technique that will undoubtedly add to the body of knowledge in natural fiber-matrix composite processing and application. The physical parameters (% water absorption, density, and hardness) as well as the mechanical properties (tensile strength, percentage elongation at break, modulus of elasticity, flexural strength, and compressive strength) of composites were also studied in this study.

METHODOLOGY

Materials, Chemicals and Equipment

Coconut husk, polystyrene foam, sodium hydroxide (NaOH), deionized water, and processing oil were among the products and chemicals employed in this investigation. Glass rod stirrer, measuring cylinder, beaker, blender, electronic weighing balance, 2 roll mill machine, compression moulding machine, Vickers Hardness tester machine, tensile tester machine, and compression tester machine are among the apparatus and equipment used.

Methods

Treatment of coconut fiber

The coconut husks were collected from the open market (*Bakin Dogo*), the central market in Kaduna, Kaduna State, Nigeria. The fibers were extracted from the coconut husk, soaked for 72 hours, and washed with water to free them from dirt and foreign materials. The fibers were later pulverised and dried at room temperature for 72 hours. The dried coconut fiber was soaked into a prepared 20% sodium hydroxide solution for 3 hours at room temperature with intermittent stirring to remove soluble lignocellulose content. After soaking, the solution was decanted and the fibers were re-washed after treatment with water to remove any alkaline solution stuck on the surface of the fibers. Finally, it was dried in the oven at 90 °C for 5 hours (Arsyad et al., 2015).

Production of composite

The treated coconut fiber (TCF) was used to reinforce polystyrene foam (PSF) to produce a composite sample through a mixing process that included the addition of recycled expanded polystyrene (polystyrene foam) while the rolls of the 2 Rolls Mill machine were turned counterclockwise and softened for 5 minutes at 170 °C. Coconut fiber was progressively introduced to the bank and cross mixed after the polystyrene foam had formed a band and bank on the front roll, and it was allowed to mix for 3 minutes. The composite resulting from the mixing process was poured into a metal mould with dimensions of 120×100×3.2 mm and shaped for 5 minutes at a controlled temperature of 150 °C and a pressure of 6 Psi on a compression moulding machine. It was then withdrawn from the hot plate and allowed to cool for 2 minutes before being expelled from the mould and labeled.

As shown in Table 1, this process was used to manufacture composite samples from treated coconut fiber with different fiber loadings ranging from 0 to 50 wt^% with a 10 weight percent interval as reinforcement. From the unreinforced composite (UC) sample to composite sample five (C5), three samples of 25×3 mm each were cut, weighed, and taken for analysis.

Table 1: Description of Composite Samples Produced

Composite Sample	Polystyrene Foam (wt%)	Treated Coconut Fiber (wt%)
UC (Unreinforced composite)	100	0
C1	90	10
C2	80	20
C3	70	30
C4	60	40
C5	50	50

Physical Properties Test

The water absorption, density, and hardness tests are the important basic physical properties of the composites that need to be quantified before the composite can be considered for any application (Eveborn et al., 2021).

Water absorption test

The water absorption test of treated coconut fiber reinforced polystyrene foam composites were done as specified by American

Society for Testing and Materials (ASTM) D5229M-12 (ASTM, 2012) as adopted by Daramola et al. (2017) by immersion in deionized water at room temperature. The samples were taken out periodically, and after cleaning out the water from the surface of the sample, it was immediately weighed using a digital weighing balance to find out the amount of water absorbed. The composites were weighed regularly at 1, 2, 3, 4, 5, 6, 7, 8, and 9 days, respectively. The water absorption was then calculated by the weight difference. The percentage weight gain of the composites was measured at different time intervals by using Equation (1).

$$\text{Water absorption}\ (\%) = \left(\frac{\mathrm{Wf}-\mathrm{Wi}}{\mathrm{Wi}}\right) \times 100 \qquad (1)$$

Where; Wi and Wf are the initial (dry) and final (wet) weights of samples (g) respectively.

Density test

The density tests of TCF/PSF composite samples were carried out by cutting the specimens at 25×25×3 mm and weighing them differently for different fiber loadings. The volume was computed by multiplying the length, the breadth, and by the thickness, as well as the density. Each specimen was measured three times differently for each sample, and the average of the results was used to determine the sample's weight. The density was then calculated using Equation (2) as follows:

$$\rho = \frac{\mathrm{W}}{\mathrm{v}} \qquad (2)$$

Where; ρ is the density (g/ml^3), W is the weight of sample (g), and V is volume of sample (ml^3) respectively.

Hardness test

The hardness testing of the coconut fiber/polystyrene foam composite samples was carried out using the Vickers Hardness Tester Machine

Model MV 1-PC, System Number 07/2012-1329, in accordance with ASTM D2240-05 (ASTM, 2005). The average of three samples of each composite tested was calculated and thereby recorded as the composite hardness value.

Mechanical Properties Test

Tensile tests such as tensile strength, percentage elongation, modulus of elasticity (MOE) at break, compressive test, and flexural strength tests are the important mechanical properties of composites that need to be quantified. Tensile test was conducted on the treated coconut fiber/polystyrene foam composite specimens using the Hounsfield Monsanto Tensometer Machine Model W6466 according to ASTM D3039-08 (ASTM, 2008) as adopted by Usman et al. (2016), and the tests such as the tensile strength, percentage elongation, and modulus of elasticity (MOE) at break were obtained from the test. Also, the flexural strength according to ASTM D7264M-07 (ASTM, 2007) and the compressive test were conducted, and three specimens were tested for each sample, and the mean was calculated and recorded as the representative value of the composite test, respectively.

RESULTS AND DISCUSSION

Physical Properties of Composites

Water absorption of coconut fiber/polystyrene foam composites

A water absorption test determines how much water is absorbed under specific conditions. Water absorption is influenced by the type of polymer used, the additive used, and the length or duration of exposure. Because of its hydrophobic nature, the unreinforced polystyrene foam (control sample) absorbed the least amount of moisture, but after reinforcing with the treated coconut fiber, the capacity to absorb moisture increased as a result of the introduction of the hydrophilic coconut fiber, as shown in Figure 1. The composites' water absorption improved as the treated coconut fiber content increased. A similar pattern has been observed in the past (Nagruib et al., 2015). Natural fibers with hydroxyl groups, such as coconut fiber, are known to absorb moisture quickly due to hydrogen bond formation. More voids are entrapped in the composites as a result of the higher fiber content, resulting in more water accumulation at the fiber-polymer matrix interface.

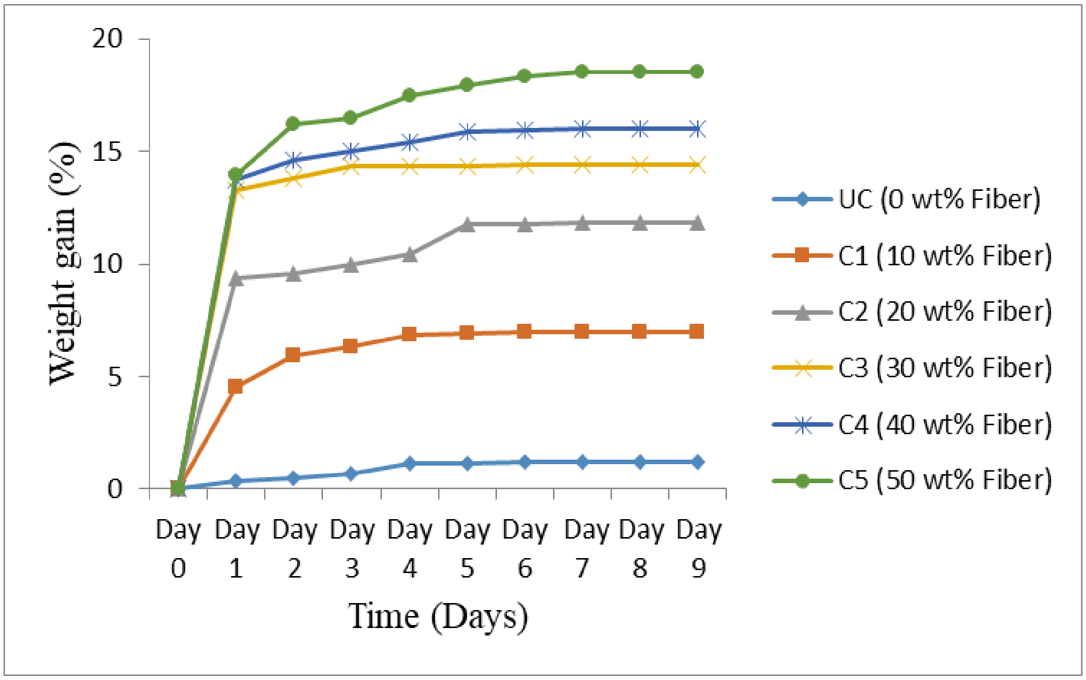

Figure 1: Water Absorption of Coconut Fiber Reinforced Polystyrene Foam Composites.

Density of coconut fiber/polystyrene foam composites

As shown in Figure 2, density increased as fiber content increased from 0.734 g/ml^3 in the unreinforced sample (0 wt%) to 1.279 g/ml^3 in the 10 wt% fibers, then decreased to 0.984 g/ml^3 (lowest density) in the 20 wt% fiber loading, and then increased to 1.519 g/ml^3 in the 30 wt% fiber loading, which has the highest density of 1.52 g/ml^3 value. Because of its light weight, a composite with a 20 wt% coconut fiber loading is excellent for future industrial applications. Because natural fibers include substantial amounts of the hydroxyl group, the result shown in the figure also demonstrates that void content in composites increases as TCF concentration increases. Because of their polar nature, natural fiber-based polymer composites absorb a lot of moisture, causing fiber swelling and gaps at the fiber-matrix interface (Geetanjali and Sandhayarani, 2016).

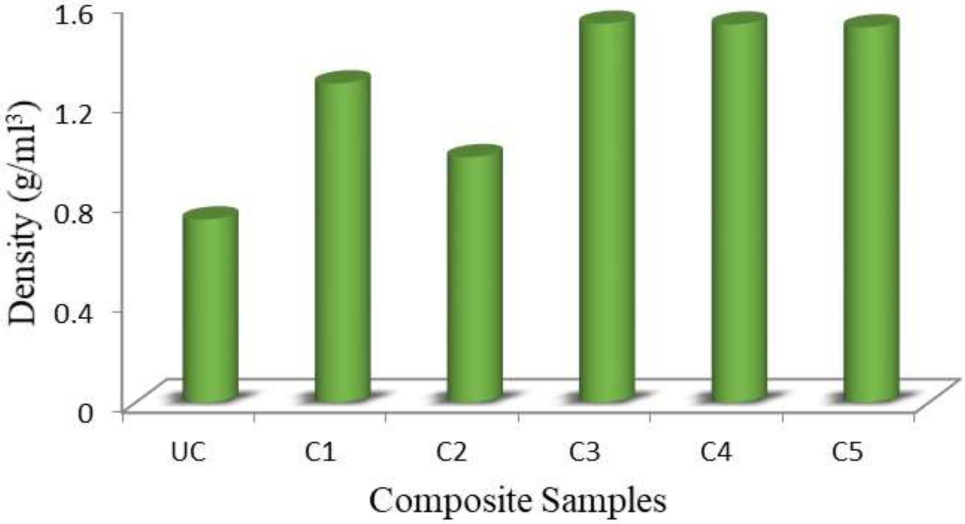

Figure 2: Density of treated Coconut Fiber reinforced Polystyrene foam Composites.

Hardness of coconut fiber/polystyrene foam composites

The influence of coconut fiber loading on the hardness of TCF employing sodium hydroxide to reinforce polystyrene foam composites is shown in Figure 3. It has been discovered that the hardness of a composite increases as the amount of coconut fiber in the composite increases. Researchers have also discovered that as fiber loading increases, composite hardness increases as well (Geetanjali and Sandhayarani, 2016). The composite with a maximum hardness of 71.54 has a 50 weight percent fiber loading, whereas the composite with the lowest hardness of 59.93 has a 10 wt% fiber loading. All composites, on the other hand, have a higher hardness than the control sample, which has a hardness of 45.83.

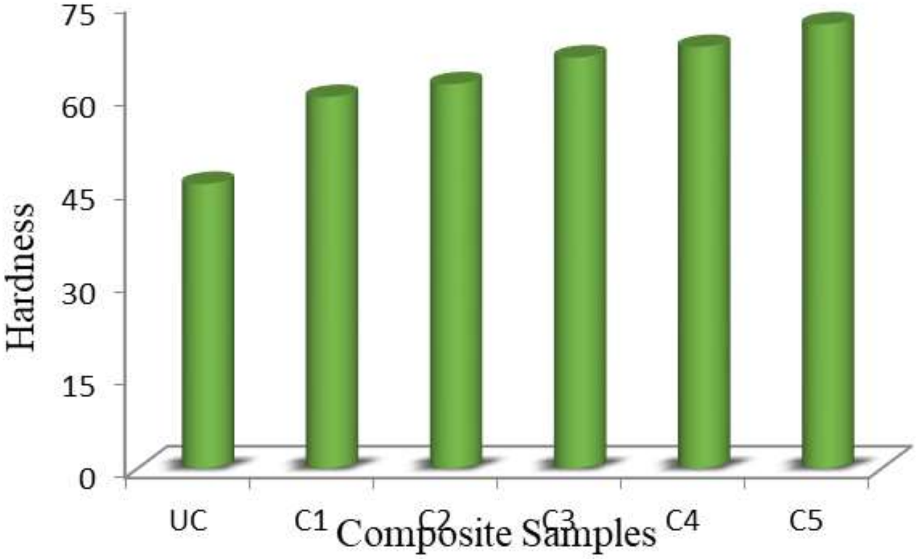

Figure 3: Hardness test of TCF reinforced Polystyrene foam Composites.

Mechanical Properties of Composites

Tensile strength of coconut fiber/polystyrene foam composites

Figure 4 depicts the effect of coconut fiber loading on the tensile strength of composites manufactured from treated coconut fiber. When compared to composites with coconut fiber loadings of 30, 40, and 50 weight percent, the composite with 20 wt% fiber content (C2) had a maximum tensile strength of 35.13 N/mm^2, which decreased when the fiber loading was increased. When compared to other composites with coconut fiber loadings of 0, 10, 30, and 40 wt%, the composite with 50 weight percent had the lowest tensile strength of 21.84 N/mm^2 because the amount of fibers inserted or incorporated was either too small or too large to support the matrix. The reduction could be attributed to fiber-fiber contact at increased fiber content when load was not properly transferred to the fiber via the matrix (Siddika et al., 2014). Inadequate interfacial adhesion between the coconut fiber and the matrix may arise as a result of the excess fiber, resulting in a loss of features.

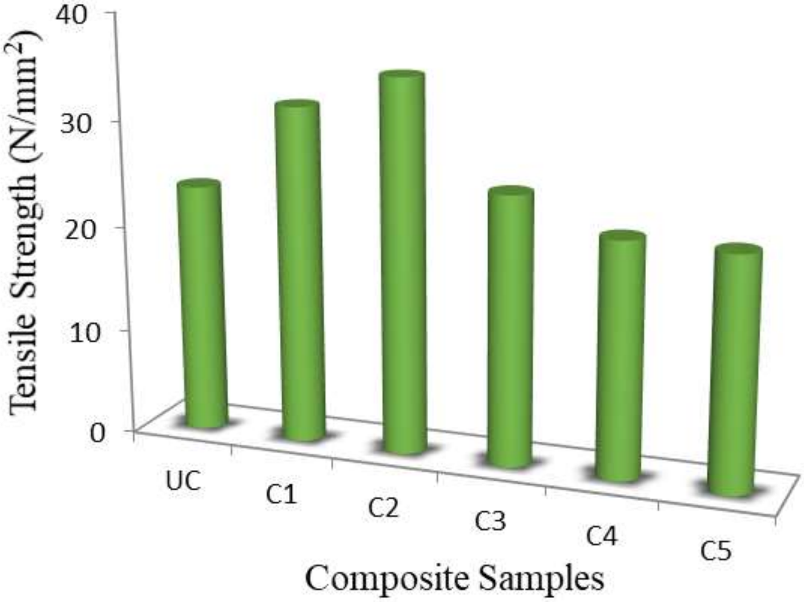

Figure 4: Tensile Strength test of TCF reinforced Polystyrene foam Composites.

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Elongation at break of coconut fiber/polystyrene foam composites

Elongation upon break is the stain left on a material or composite after it breaks. It is usually expressed in percentages and is a measure of the material's ductility. From an engineering standpoint, elongation at breaks is an important property in understanding the rupture behaviour of composite materials. Figure 5 depicts the effect of fiber loading on the elongation at break of treated coconut fiber and polystyrene foam composites after treating with NaOH. Any of the coconut fiber reinforced composites showed a higher percentage elongation than the control sample (unreinforced PSF).

The percentage elongation at break decreases linearly as the coconut fiber content increases, with the highest elongation at break of 16.90 percent in the composite sample with 10 weight percent fiber content and the lowest elongation at break of 11.67 percent in the composite sample with 50 wt% coconut fiber. Because the fibre is stronger than the matrix, the polymer-polymer chain is broken by the fiber, resulting in lower elongation. The highest percentage elongation in this study was 16.90 percent, compared to 0.94 percent and 1.98 percent for luffa and Dum palm fiber reinforced polyester composites, respectively (Sunmonu et al., 2014)..

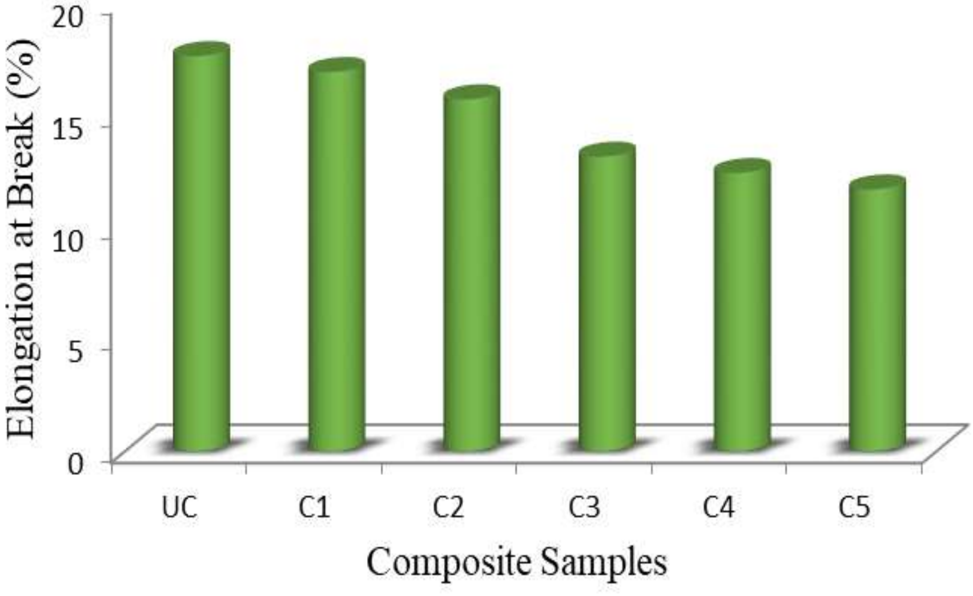

Figure 5: % Elongation at break of TCF reinforced Polystyrene foam Composites.

Compressive strength of coconut fiber/polystyrene foam composites

As shown in Figure 6, the compressive strength of PSF composites reinforced with TCF increases with increasing fiber content from 10 wt% (C1) to 40 wt% (C4) treated coconut fiber before starting to decreases. The strength of the composites increased from 9.18 MPa in the 0 wt% (UC) fiber loading sample to 19.44 MPa in the 40 wt% treated coconut fiber loading sample before dropping to 14.68 MPa in the 50 weight percent (C5) TCF content sample. The composite material required more energy to break than the control sample, which was made entirely of polystyrene foam.

Increased fiber surface roughness leads to greater mechanical interlocking and more cellulose exposed on the fiber surface, resulting in increased compressive strength (Shehu et al., 2017). On the other hand, all of the composite grades, on the other hand, had higher compressive strength and stiffness than the unreinforced PSF matrix, showing that adding TCF after treating with NaOH to polystyrene foam composites improves their compressive strength. The observed trend could be related to a rise in the stiffness of the composite when the fiber content was increased (El-Shekeil et al., 2014).

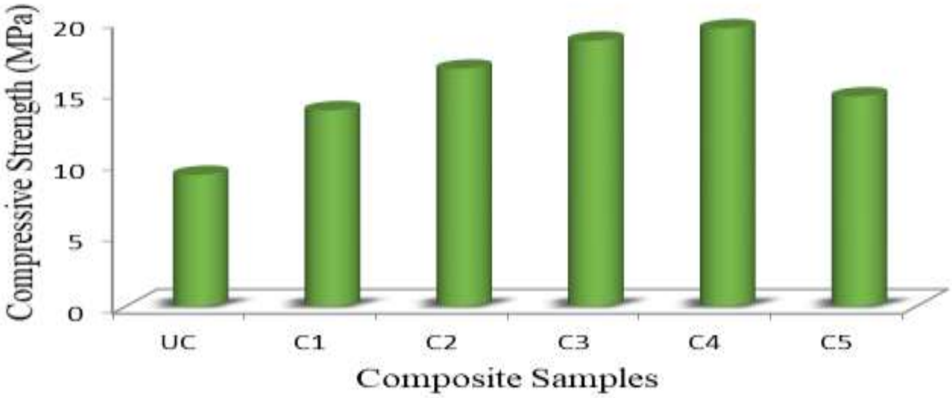

Figure 6: Compressive Strength Test of TCF-reinforced Polystyrene Foam Composites.

Modulus of elasticity at break of coconut fiber/polystyrene foam composites

Figure 7 depicts the influence of treated coconut fiber using 20% NaOH on the modulus of elasticity (MOE) reinforced polystyrene foam. The modulus of elasticity increases with increasing the volume fraction of TCF up to 20 weight percent, with a modulus of elasticity of 272.32 N/mm^2 in the composite with 30 weight percent treated coconut fiber. This means that the 20 wt% fiber loading composite has the highest degree of stiffness of all the fiber loadings investigated. The decrease in modulus of elasticity above 20 weight percent could be due to poor interaction between constituents and poor dispersion of fiber loading in the matrix (Daramola et al., 2017 and Shehu et al., 2017). All of the composite grades, however, had higher flexural stiffness than the unreinforced polystyrene foam matrix, showing that adding TCF enhances the modulus of elasticity of polystyrene foam composites.

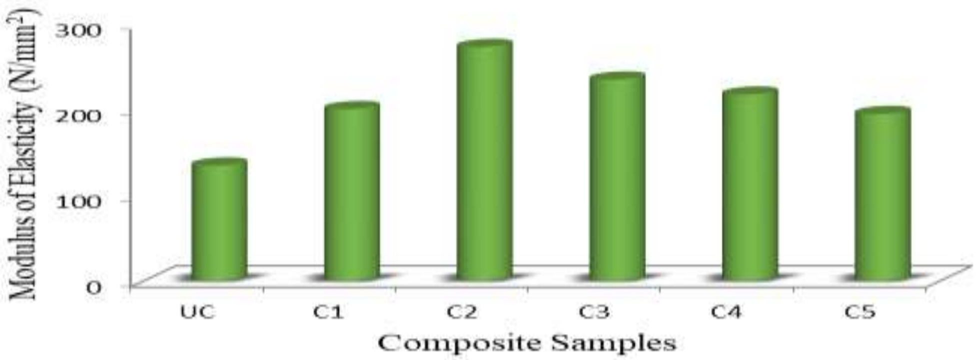

Figure 7: Modulus of Elasticity of TCF reinforced Polystyrene foam Composites.

Flexural strength of coconut fiber/polystyrene foam composites

The flexural property of composites is one of the most important characteristics, and it is largely used to quantify them in structural applications. Flexural strength refers to a material's capacity to withstand bending or twisting loads. The flexural strength of the unreinforced (0 wt% fiber content) and reinforced composites is shown in Figure 8. When the volume percentage of treated coconut fiber using NaOH is increased by up to 20 wt%, flexural strength increases until it starts to fall. The flexural strength of the generated composite increased from 140.34 N/mm^2 in the 0 wt% TCF composite sample to 210.81 N/mm^2 in the 20 weight percent treated coconut fiber composite sample. This improvement can be attributed to enhanced fiber/matrix adhesion.

A decrease in wettability caused by excessive fiber loading, on the other hand, can be linked to a minor decreased in bending strength above 20 wt% TCF loading. Due to the resin's failure to properly moisten the fibers, flexural strength is reduced slightly. According to the findings, the increase in flexural strength from 0 to 20 weight percent fiber content before it began to decline followed an opposite trend to the tensile strength, modulus of elasticity, and stiffness values. In general, composite samples with fiber loadings of 10 and 20 weight percent flexural strength were higher than control samples (0 wt% coconut fiber content), showing that coconut fibers improve composite flexural strength by supporting pressures acting transversely to the composite axis.

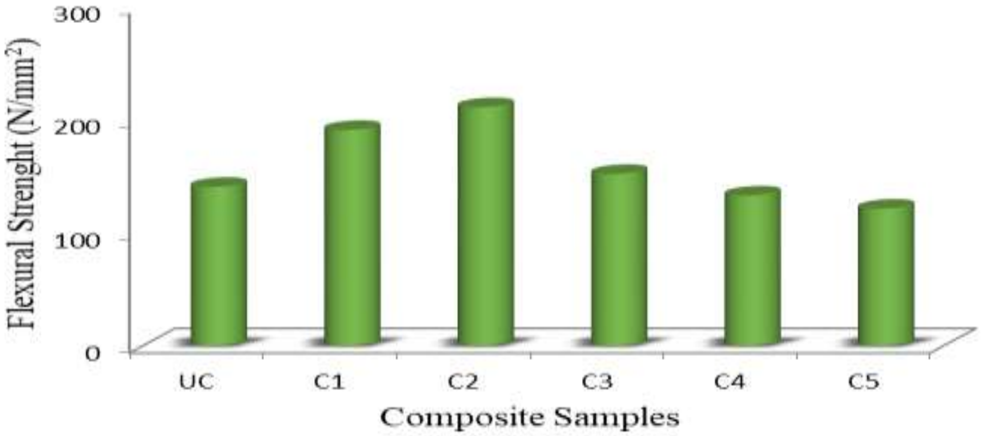

Figure 8: Flexural Strength test of TCF reinforced Polystyrene foam Composites.

CONCLUSION

The current study shows that the fiber parameters have a significant impact on the characteristics of treated coconut fiber reinforced PSF, suggesting that coconut fiber treatment using NaOH can be used as reinforcement in polystyrene foam to build composites. The density, water absorption, and hardness of composites increase as the fiber content increases. The tensile properties of composites, such as tensile strength, modulus of elasticity, and flexural strength, increase with increasing reinforcement fiber loading up to 20 weight percent treated coconut fiber content for compressive strength and 40 weight percent fiber content for tensile strength before starting to decrease due to better wettability and a good interfacial bond between the coconut fiber and polystyrene foam. The optimal fiber content for improved or superior mechanical properties has been determined to be 20 percent by weight. Furthermore, as the percentage elongation at break of composites increased, the percentage elongation at break decreased. Coconut fiber reinforced polystyrene foam composites fabricated with 20 wt% treated coconut fiber have better fiber/matrix adhesion, making them suitable for built-up and engineering applications.

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