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ASSESSMENT OF THE PHYSICAL, MECHANICAL AND WEAR PROPERTIES OF GRASS-CUTTER (THRYONOMYS SWINDERIANUS) KERATINOUS HAIR FIBER BASED POLYPROPYLENE COMPOSITES

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Animal fiber; Biodegradable; Agro-waste; Lightweight material; Surface modification.

ABSTRACT

This work aim at investigate the influence of grass-cutter hair fiber (GHF) as reinforcement in polypropylene (PP) composites. The mechanical and water absorption behaviour of the fabricated GHF/PP composites were investigated. From the result, it was observed that at low weight fraction of GHF after treatment, both the mechanical and wear properties were enhanced, which may be attributed to the removal of waxy materials from the fiber surfaces and the addition of oxygenated functional group at the surface and edges of the fibers. While the water absorption capacity of the composites was enhanced due to the presence of hierarchical micro-pores in the composites. Hence, the composites can be used as light-weight engineering materials for automobile applications.

1. INTRODUCTION

Fiber reinforced polymeric composite is a material consisting of a polymer matrix in which fibers are independently dispersed. The polymer matrix provides the necessary adhesion sufficient to hold the embedded fiber in position. Polymers are short of required physio-mechanical properties required for material performance. Hence, high strength fibers are introduced to enhance these properties. Reports have shown that fiber based polymeric composites are currently utilized for packaging, automobile, aerospace, construction, marine and biomedical (Dipen et al,. 2019; Srinivas, 2017; Ku et al., 2011).

Fibers can either be synthetic or natural. Synthetic fibers are made by polymerizing fiber forming monomers and then extruding them into thread-like structures. Conventional synthetic fibers that have been used to reinforce polymers are carbon, glass, kevlar (aramid) and basalt. Improvement in mechanical, wear and corrosion

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resistance, and thermal properties have been reported with the use of synthetic fibers for polymeric composites because synthetic fibres possess inherent good strength, high wear resistance and fatigue life (Manikandan & Rajkumar, 2016). However, the shortcoming of synthetic fiber lies in their high cost, high density, difficulty to recycle and non-biodegradability (Begum & Islam, 2013**).** These drawbacks limit the continuous usage of synthetic fibers for polymer composite development and have stimulated the quest to investigate potential alternatives which will be cost effective and environmentally benign natural fiber (Oladele et al., 2010).

Natural fibers are gotten from readily available renewable sources usually plants and animals. Some of the investigated natural fibers are sisal, bagasse, hemp, coir, jute, flax, pineapple-leaf, okra, abaca, rice husk, wheat husk, kenaf, bamboo, banana, animal hairs/fur, fleece, silk. Natural fibres are attractive fillers because of their promising properties such as low density, recyclability, biodegradability, non-toxicity and eco-friendliness (Begum et al., 2013; Nguong et al., 2013; Arrakhiz et al., 2012; Oladele et al., 2014; Oladele & Agbeboh, 2017). These properties offer the advantage of producing mechanically robust and biodegradable materials at reduced cost. Thus, making the addition of low cost and readily available natural fibers vital in material production and also as potential substitute for expensive synthetic fibers (Zini & Scandola, 2011). For better property optimization and to improve the interfacial bonding between hydrophilic natural fibers and hydrophobic polymer matrix, fiber pretreatment is recommended (Chandekar et al., 2020; Komal et al., 2018). Chemically, fiber pretreatment helps to reduce the hydrophilicity of the fiber while physically removing waxy materials covering the fiber surface in order to change the fiber texture (Moyeenuddin et al., 2011; Malkapuram et al., 2009).

Grass-cutter hair fiber (GHF), a natural fiber from animal origin, is a coarse and bristly fur. It is gotten as a waste by-product obtained during the processing of "greater cane rat", a rodent of genus *Thryonomus* and species *swinderianus*, native to the savanna area in West Africa and often domesticated as a source of "bush meat". This rat is relatively found in most part of Africa countries, most especially in Ghana and Nigeria. GHF is conventionally disposed by either burning or burying and both means contribute adversely to environmental and public health.

Until recently, there are no available studies on the use of GHF for material development. Therefore, in bid to evaluate the feasibility and viability of GHF for polymer composite development, we examine the influence of GHF on the mechanical, wear and water absorption properties on polypropylene (PP) matrix composite. PP is among the most studied thermoplastic for polymer matrix composite due to its cheapness, strength and ease of processing. However, its tensile and flexural properties are not good enough for many engineering applications. Thus, the need for reinforcement to enhance the mechanical and wear properties.

In this work, the influences of GHF, a keratinous fiber, on the mechanical, wear and water absorption properties of polypropylene composites were investigated. Also, we examine the effect of surface pretreatment on the property enhancement of the GHF/PP composite.

2. MATERIALS AND METHODS

2.1 Materials

Grasscutter hair was locally sourced from a farmland in Akure, Ondo State, South-West, Nigeria. The larger specie, *Thryonomys swinderianus* that was used has a head-and-body length of up to 60 cm. The polypropylene, dioctyl phthalate, stabilizer zinc stearate, and hydrogen peroxide were bought from Pascal Scientific Chemicals, Akure, Ondo State.

2.2 Methods: Processing of grass-cutter hair fiber (GHF)

GHF was extracted by scraping the hair from the body (Plate 'a') using hot water; the debris present in the fiber were removed by washing and sun drying for 72 hours. The GHF were chopped into 10 mm length (Plate 'b') was divided into two equal halves. One of the halves was treated with 0.15 M H_2O_2 at 50 ^oC for 1 hour in a water bath shaker. Afterward, the treated fibers were washed and rinsed with distilled water. The fiber pH was kept around (Komal et al., 2018) (Malkapuram et al. (2009). Finally, the treated fibers were sun dried before use in composite development.


(a)


(b)

Plate 1. (a) Grass-cutter (greater cane rat) (b) Grass-cutter hair fiber

2.3. Composite development

The GHF/PP composites were fabricated with the help of compression moulding machine. Various wt% (3, 6, 9, 12 and 15 wt %) of fibers were independently dispersed in the polypropylene resin matrix while the plasticizer and stabilizer were introduced in 2:1. The GHF/PP composites were maintained at 170 °C for 6 minutes for each sample in the compression moulding machine before they were taken out and allowed to solidify, cool and cure in air for 10 minutes before removing the produced samples from the mould. The untreated GHF/PP were fabricated following the same procedure. Tensile, flexural, wear and water absorption tests were carried out to determine the mechanical and tribological properties of the GHF/PP composites.

2.4. Determination of GHF density

The density of GHF was determined with the implementation of Archimedes' principle. The mass of a sizable quantity (20 g) of GHF was determined using digital metric weight balance (Precision: 0.0001 g) and denoted as M_s. The graduated measuring cylinder (500 ml) was then filled with about 200 ml of distilled water and this was recorded as the initial volume (V_0). The already weighed GHF was then immersed into the measuring cylinder containing 200 ml of distilled water. The new water volume was recorded and denoted as V_1. The volume of water displaced (V_{fl}) by the GHF was calculated as follows: V_1 - V_0. This value (V_{fl}) was used to determine the mass of the displaced fluid (M_{fl})using eq. 1

$$M_{fl} = \rho_{fl} x V_{fl} \qquad (1)$$

Where V_{fl}- volume of fluid displaced; M_{fl}- mass of fluid displaced; ρ_{fl}- density of fluid (1 g/cm^3). The mass (M_{fl}) was used to determine the density of the GHF (ρ_s) using the Archimedes' principle as shown in eq. 2.

$$\rho_s = \rho_{fl} \cdot \frac{M_s}{M_{fl}} \qquad (2)$$

Where ρ_s- density of GHF; M_s-mass of GHF, M_s= 20 g, M_{fl}= 47 g, ρ_{fl} = 1 g/cm^3. The density of the GHF (P_s) was calculated to be 0.4255 g/cm^3.

2.5. Aspect ratio of GHF

The aspect ratio describes the ratio of the length of the fiber (L) to its diameter (D). For this work, the average diameter of the GHF was used. This in turn was used to compute the aspect ratio as shown in eq. 3.

$$\text{Aspect Ratio} = \frac{L}{D} \qquad (3)$$

Where, L = 29.348, D = 0.196
The aspect ratio was calculated to be 149.735

2.6. Fiber Fineness

Fiber fineness refers to the ratio of mass per unit length of the fiber. The fiber fineness is influenced by density and diameter. The fineness of the fiber was calculated using eq. 4 (Steinmann & Saelhoff. 2016).

$$T = \frac{\pi \rho D^2}{4} \qquad (4)$$

Where, D – Diameter; ρ – Density; T – fiber fineness and, D =0.0196 cm, ρ= 0.4285g/cm^3. The titer of the grasscutter hair fiber was determined to be $1.293 \text{ x} 10^{-4}$ g/cm.

2.7 Tensile test

The tensile behaviour of the composites was evaluated with the aid of tensile test performed in accordance with ASTM D3039/D3039M-17 (West Conshohocken, PA, 2017). ASTM D3039 / D3039M-17), a standardized test method for tensile properties of polymer matrix composite materials.

2.8 Flexural test

Universal testing machine was used to carry out the flexural test in accordance to ASTM D790-03 (West Conshohocken., 2003). ASTM D790-03). A sample cut into 150 x 50 x 5mm was placed in grip of the machine and was stretch at a test speed of 5 mm/min over a span of 65.00 mm.

2.9 Impact Test

The notched Izod impact test was conducted in accordance with ASTM D256-10 (West Conshohocken, 2018).) a standardized test method for determining the Izod Pendulum impact resistance of plastics. The test was carried out using a Hounsfield balanced impact testing machine, serial number 3915, model number h10-3. The test samples were placed in a cantilever position, clamped upright with a V- notch at the level of the top of the clamp. The machine pendulum hit the test piece and was allowed to fall freely to a fixed height.

2.10 Wear Test

Wear test was performed to evaluate the wear property of a material to determine the suitability of the composite for specific wear application. The samples were evaluated using the Taber abrasive tester model TSC-A016 in accordance with ASTM D 1044-13 (West Conshohocken, 2013), a standardized test method for resistance of transparent plastics to surface abrasion. Prior to the test, the initial weight of the sample was measured. Each sample was mounted on the Taber abrasive tester operated at 150 rpm for 10 mins, and then the weight post abrasion testing was taken. A mould of 100 mm diameter x 4 mm thickness was used to produce the wear samples. The wear index (W.I) was determined from eq. 5.

$$(W.I) = \frac{initial\ weight - final\ weight}{time\ of\ test\ cycle}\ x\ 100 \qquad (5)$$

The wear index indicates the rate of wear calculated by measuring the loss in weight in milligrams per test cycles of abrasion.

2.11 Water absorption test

The water absorption behavior of the GHF/PP composite was evaluated in accordance with ASTM D5229M-12 (West Conshohocken. 2012).). The initial weight of the samples was measured before immersing in distilled water. At every 24 hours, the sample was cleaned, and new weight was measured at every interval of 24 hours until the saturation level was reached where there was no significant increase in weight was noticed. In this case it was after 7 days. The percentage (%) water absorption was computed using eq. 6

$$W = \frac{W_t - W_0}{W_0}\ \text{x}\ 100 \qquad (6)$$

Where W- is the % water absorption, W_t and W_0- final and initial weight after time t

3. RESULT AND DISCUSSIONS

3.1 Physical Properties

The uniqueness of natural fibers was predominant in the GHF length and diameter as shown in Table 1. Three major sections were identified and measured within a single GHF length. The physical properties of the fibers were determined and presented in Table 2. Notable among this is the density of the fiber which was very low compared to the matrix (density of polypropylene is between 0.895−0.92 g/cm^3. Therefore, incorporating this into the PP will make the composites to be lighter than the mono-material.

Table 1. Average hair length and diameters of GHF

Length (mm)	Base diameter (mm)	Middle diameter (mm)	Tip diameter (mm)
29.348	0.164	0.196	0.123

Table 2. Physical properties of GHF

Length (mm)	29.348±0.709
Diameter at mid (mm)	0.196±0.007
Density (g/cm^3)	0.4285
Aspect ratio	149.735
Fiber fineness	$1.293\ x\ 10^{-4}$

3.2 Tensile Properties

Ultimate tensile strength (UTS)

Figure 1 shows the ultimate tensile strength (UTS) of the GHF/PP composites. The treated GHF/PP with 3 wt% of GHF has a UTS of 40.22 MPa which is about 21% enhancement over the neat sample. It was also observed that treated GHF produces the higher UTS for each of the weight fraction than their corresponding untreated GHF. This enhancement in UTS can be attributed to surface functionalization using hydrogen peroxide which chemically modify the GHF surface and edges. The high aspect ratio of GHF and chemical modification of the GHF surface account for improve wetting of the fiber by the matrix and enhance interfacial bonding (Chandekar et al., 2019). Likewise, the change in fiber texture fosters the fiber-PP interlocking, thereby enhancing adhesion. This aid the independent dispersion of fiber within the matrix which support load transfer from the matrix to the treated GHF additive and contribute to load bearing capacity of the composite and resistant to deformation.

Although the UTS of the GHF/PP composites tend to decrease with increase in fiber loading for both treated and untreated GHF reinforced PP. The decrease in the UTS is due to lack of uniform dispersion with increasing GHF loading. This causes poor interfacial adhesion between the polymer matrix and fiber reinforcement which result in fiber debonding during the stress. Notwithstanding, the UTS values for all the GHF/PP composites are higher than that of the neat sample. This shows that GHF addition improve the UTS of PP composite.

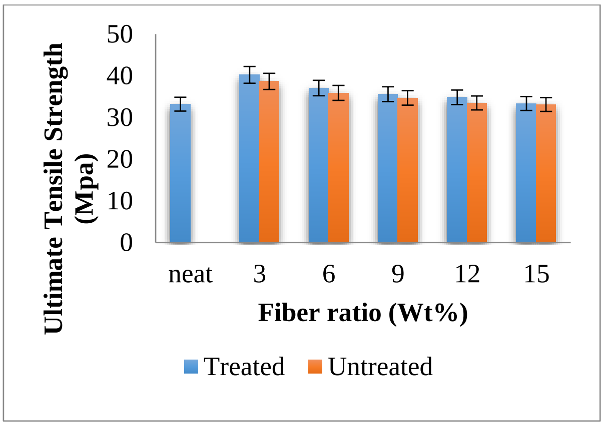

Figure 1. Ultimate tensile strength of the developed composites and neat sample

Tensile modulus (Young's modulus)

The tensile modulus of the fabricated composites is shown in Figure 2. About 81% and 57% increment was observed using 3 wt% of treated and untreated GHF. Proper adhesion between the chemically modified GHF with 3wt% result in 24% improvement over the untreated GHF with same wt% loading. This further confirm the essentiality of treating GHF before introducing to the polymer matrix. The result shows that the Young's modulus (stiffness) of polypropylene can be enhanced by incorporating GHF as reinforcement. The result also reveals that when the wt% of GHF exceed 9%, there is no improvement. This may be due to GHF reaching it threshold value at 9wt%, indicating that further increase in wt% of GHF will not result in any improvement of the composite. Thus, it can be deduced from the observation that the wt% of GHF loading for load bearing application should not exceed 9% and for better performance, the GHF should be treated.

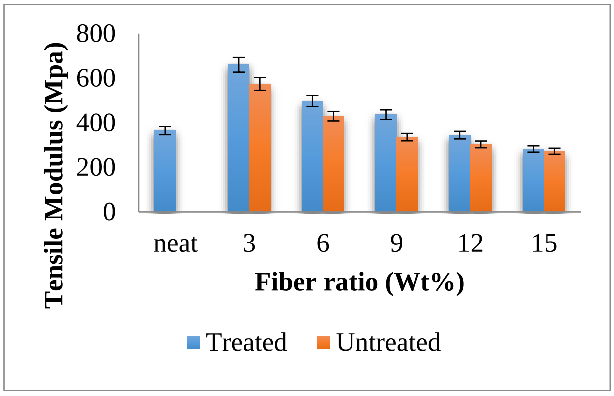

Figure 2. Tensile modulus of the developed composites and neat sample

Figure 3 shows the tensile strain of GHF/PP composites and the neat sample. The increasing tensile strain due to increase in GHF loading can be attributed to inverse relationship between tensile modulus and strain. From the tensile modulus result, it is shown that stiffness decreases with increase in GHF addition for all the GHF/PP composites. Since there is a decrease in stiffness of the GHF/PP composite, the tensile strain is expected to increase with increasing wt% of GHF. The same phenomenon applies to the strain result of treated and untreated GHF/PP composites. Untreated GHF/PP composites tends to have higher tensile strain than their corresponding treated GHF/PP composites due to lower tensile modulus.

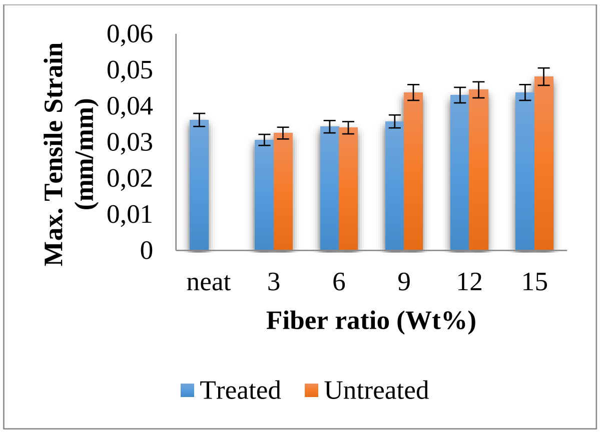

Figure 3. Tensile strain of GHF/PP composites and neat sample

3.3 Flexural Properties

Flexural strength

The flexural strength at peak of the neat and GHF/PP composite is shown in Figure 4. Treated GHF/PP composites with 3-9 wt% yield better flexural strength than the neat and corresponding untreated GHF/PP composites. It was observed from GHF/PP composites with 3 wt% of the treated GHF gives the best result with about 34.5% and 10.6% enhancement over the neat and 3wt% untreated GHF/PP composite respectively. The improvement in flexural strength is due to effective stress transfer between the stiff GHF and PP matrix as a result of their good interfacial bonding. Composition with 12 and 15 wt% of GHF tends to have lower flexural strength. This is due to agglomeration as a result of excessive GHF loading.

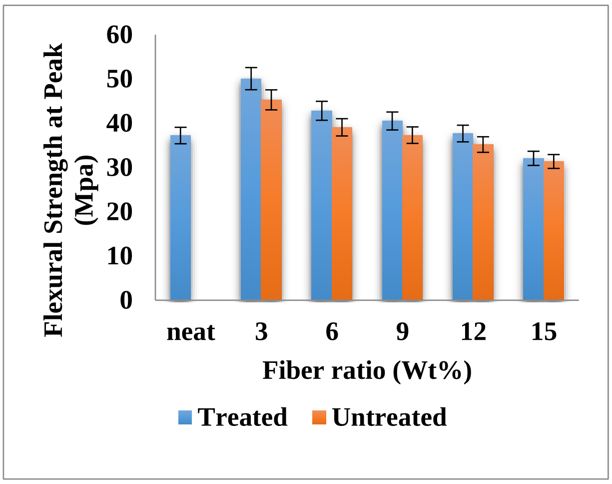

Figure 4. Flexural strength at peak of GHF/PP composites and neat sample.

Flexural modulus

Figure 5 shows the flexural modulus of the neat and GHF/PP composites. It can be observed that GHF/PP composites have better flexural strength than the neat PP sample. GHF/PP composite with 3 wt% GHF has about 32% flexural strength enhancement over the neat sample. Likewise, the treated GHF/PP possess higher flexural modulus than their corresponding untreated GHF/PP composites. The result also shows that flexural modulus of the GHF/PP composites decreases with increase in GHF addition. This trend can be attributed to poor dispersion as a result of excess loading which makes the GHF reinforced composite prone to debonding when load is applied.

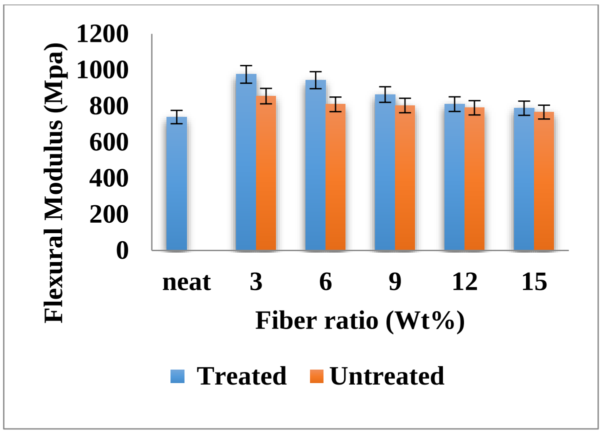

Figure 5. Flexural modulus of GHF/PP composites and neat sample

3.4 Impact Energy

Figure 6 shows the impact energy, material's ability to withstand sudden load/shock, of the neat and GHF/PP composites. It can be observed that the impact energy of all the treated GHF/PP composites were substantially enhanced. It is interesting to know that the effect of increasing GHF addition to PP matrix was not pronounced in the treated GHF/PP composites. This is due to the improved interfacial bonding between treated GHF-PP which causes the GHF to be interlocked within the PP matrix, thus resisting the propagation of crack during the application of sudden load. Also, GHF has shock attenuation effect which diminishes the magnitude of impact load as it propagates along the composite.

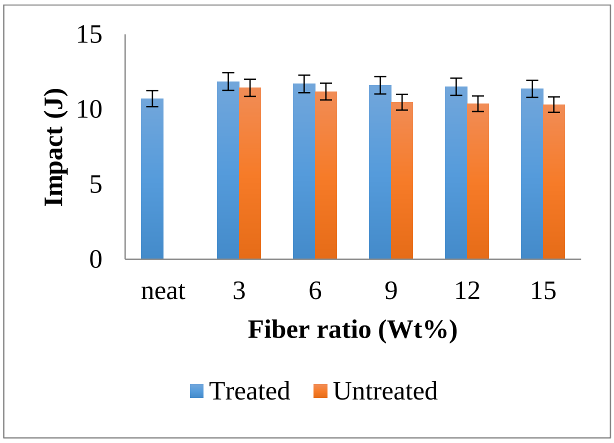

Figure 6. Impact energy of GHF/PP composites and neat sample

3.5 Wear Behaviour

The wear behaviour of the fabricated composite is shown in Figure 7. The result shows that addition of treated GHF to PP matrix remarkably decrease the wear rate with 3 wt% of treated GHF/PP being the best having about 140% enhancement over the neat sample. The improvement is due to resistance to wear offered by the GHF during abrasion. Also, the result shows that pretreatment of GHF aid good wettability and strengthen the interfacial bonding. Treated GHF are held firmly within the matrix thereby preventing fiber detachment or pull out during abrasion. This indicate the potential and prospect of utilizing treated GHF reinforced composite for applications prone to friction or tribological loading environment. In contrast, untreated GHF-PP have less resistance to abrasion and the effect is conspicuous with increase in fiber loading.

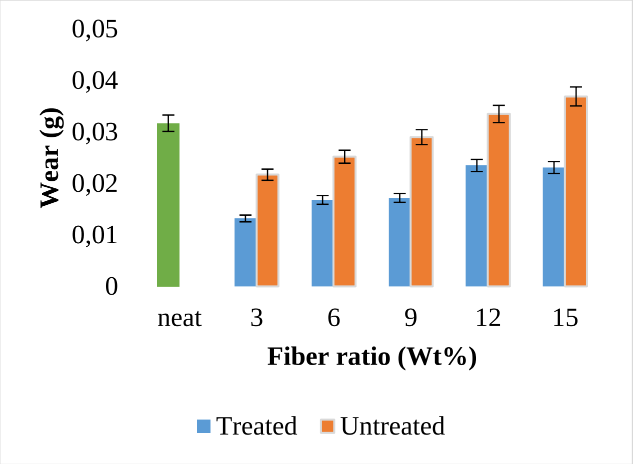

Figure 7. Wear property of GHF/PP composites and neat sample

3.6 Water absorption properties

The treated GHF/PP composites (Figure 8) appears to be hydrophobic than the untreated GHF/PP composites (Figure 9) due to the chemical modification of GHF and the addition of functional groups to GHF surface. The low absorption capacity of neat sample can be attributed to the hydrophobic nature of PP (Komal et al., 2018).

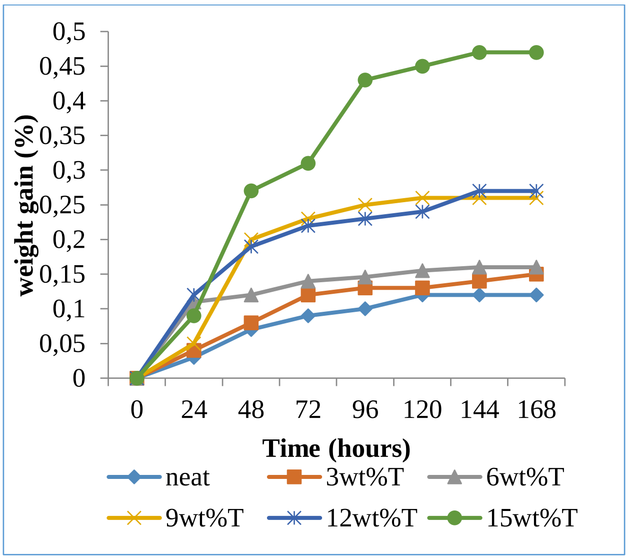

Figure 8. Water absorption of treated GHF/PP composites and neat sample

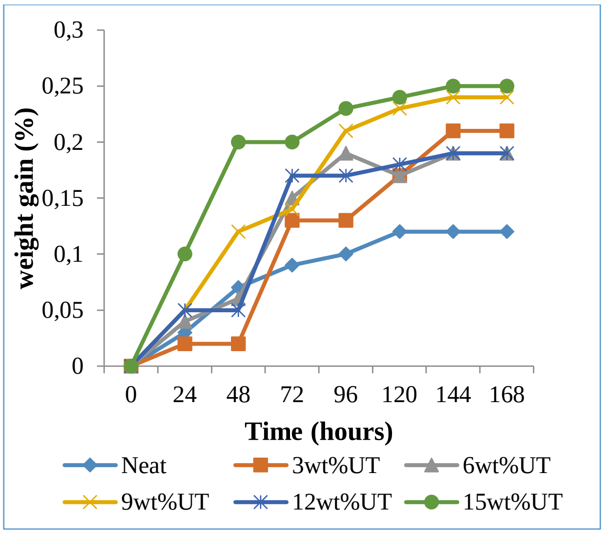

Figure 9. Water absorption of untreated GHF/PP composites and neat sample

From the result, it is observed that the longer the samples stay in water, the more water they absorb. The neat sample attains a saturation point after 120 hours while the GHF/PP composites have an anomalous water absorption behaviour. The anomalistic water absorption behaviour of the GHF/PP composites can be due to diffusion of water into the hierarchical micro-pores in the composites. The increase in water absorption with increasing wt% of GHF is as a result of water affinity by the hydrophilic GHF (Tajvidi M., Najafi S.K., & Moteei N. 2006). Thus, the more the fiber content, the higher the rate of water absorbed. Notwithstanding, composite with low wt% of treated GHF have less micro-pores than those with higher wt% as evidence in their lower affinity for water when compared to other GHF/PP composites.

4. CONCLUSION

The effect of GHF on the mechanical, wear and water absorption behaviour of PP have been investigated. The result shows that treated GHF/PP gives better performance than untreated GHF/PP composites and reinforced composites perform better than the unreinforced polypropylene. Also, GHF/PP composites containing 3-9 wt% of treated GHF possess good mechanical, wear and water absorption behaviour with GHF/PP having 3 wt% of treated GHF being the best composite. The research work shows that low wt% of treated GHF should be introduced to polymer matrix for better property optimization. In addition, the project shows that GHF can be a potential alternative reinforcement for polymer composites suitable for light weight structural applications.

References:

Arrakhiz, F. Z., Elachaby, M., Bouhfid, R., Vaudreuil, S., Essassi, M., & Qaiss, A. (2012). Mechanical and thermal properties of polypropylene reinforced with Alfa fiber under different chemical treatment. *Materials and Design*, *35*, 318-322. doi.org/10.1016/j.matdes.2011.09.023

Begum, K., & Islam, M. A. (2013). Natural Fiber as a substitute to Synthetic Fiber in Polymer Composites. *Research Journal of Engineering Sciences*, *2*(3), 46-53.

Chandekar, H., Chaudhari, V., Waigaonkar, S., & Mascarenhas, A. (2020). Effect of chemical treatment on mechanical properties and water diffusion characteristics of jute-polypropylene composites. *Polymer Composites*,*41*(4), 1447-1461. doi.org/10.1002/pc.25468

Dipen, R., Durgesh, P., Pradeep M., & Emanoil, L. (2019). Fiber-Reinforced Polymer Composites: Manufacturing, Properties and Applications. *Polymers*, *11*(10), 1667. doi.org/10.3390/polym11101667

Komal, U. K., Verma, V., Ashwani, T., Verma, N., & Singh, I. (2018). Effect of Chemical Treatment on Thermal, Mechanical and Degradation Behavior of Banana Fiber Reinforced Polymer Composites. *Journal of Natural Fibers*, 1-13. doi.org/10.1080/15440478.2018.1550461

Ku, H., Wang, H., Pattarachaiyakoop, N., & Trada, M. (2011). A review on the tensile properties of natural fiber Reinforced polymers composites. *Compos Part B – Engineering*, *42*(4), 856-873. doi.org/10.1016/ j.compositesb.2011.01.010

Malkapuram, R., Kumar, V., & Negi, Y. S. (2009). Recent Development in Natural Fiber Reinforced Polypropylene Composites. *Journal of Reinforced Plastics and Composites*, *28*(10),1169-1189. doi.org/10.1177/0731684407087759

Manikandan, A., & Rajkumar, R. (2016). Evaluation of Mechanical Properties of Synthetic Fiber Reinforced Polymer Composites by Mixture Design Analysis. *Polymers & Polymer Composites*, *24*(7), 455-462. doi.org/10.1177/096739111602400702

Moyeenuddin, A., Sawpan, M. A., Pickering, K. L., & Fernyhough, A. (2011). Effect of various chemical treatment on the fiber structure and tensile properties of industrial hemp fibers. *Compos Part A – Applied Science and Manufacturing*, *42*(8), 888-895. doi.org/10.1016/j.compositesa.2011.03.008

Nguong, C. W., Lee, S. N. B., & Sujan, D. (2013). A Review on Natural Fibre Reinforced Polymer Composites. *International Scholarly and Scientific Research & Innovation*, *7*(1), 52-59.

Oladele, I. O., & Agbeboh, N. I. (2017). Development of Mathematical Models and Estimation for the Mechanical Properties of Organic Fiber Reinforced Polyester Composites, *Fibers and Polymers*, *18*(7). 1336-1345. doi: 10.1007/s12221--017-1064-2

Oladele, I. O., Okoro, A. M., Omotoyinbo, J. A., & Khoathane, M. C. (2018). Evaluation of the Mechanical Properties of Chemically Modified Chicken Feather Fibres Reinforced High Density Polyethylene Composites. *Journal of Taibah University for Science*, 2018, 1-9. https://doi.org/10.1080/16583655.2018.1451103

Oladele, I. O., Omotoyinbo, J. A., & Adewara, J. O. T. (2010). Investigating the Effect of Chemical Treatment on the Constituents and Tensile Properties of Sisal Fibre. *Journal of Minerals & Materials Characterization & Engineering*, *9*(6), 569- 582.

Oladele, I. O., Omotoyinbo, J. A., & Aiyemidejor, S. H. (2014). Mechanical Properties of Chicken Feather and Cow Hair Fibre Reinforced High Density Polyethylene Composites, *International Journal of Science and Technology*, *3*(1), 66-72.

Srinivas, K. (2017). A Review on Chemical and Mechanical Properties of Natural Fiber Reinforced Polymer Composites**.** *International Journal of Performability Engineering*, *13*(2), 189-200. doi.org/10.23940/ijpe.17.02.p8.189200

Tajvidi, M., Najafi, S. K., & Moteei, N. (2006). Long-Term Water Uptake Behavior of Natural Fiber/Polypropylene Composites. *Journal of Applied Polymer Science*, *99*(5), 2199-2203. doi.org/10.1002/app.21892

West Conshohocken, PA, (2018). ASTM D256-10(2018): Standard Test Methods for Determining the Izod Pendulum Impact Resistance of Plastics, ASTM International. doi:10.1520/D0256-10R18

West Conshohocken, PA, (2017). ASTM D3039 / D3039M-17: Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials, ASTM International. doi:10.1520/D3039_D3039M_17

West Conshohocken, PA, (2013). ASTM D1044-13: Standard Test Method for Resistance of Transparent Plastics to Surface Abrasion, ASTM International. doi:10.1520/D1044-13

West Conshohocken, PA, (2012).ASTM D5229/D5229M-12, Standard Test Method for Moisture Absorption Properties and Equilibium Conditioning of Polymer Matriax Composite Materials. ASTM International. doi:10.1520/D5229_D5229M

West Conshohocken. PA. (2003). ASTM D790-03: Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials, ASTM International. doi:10.1520/D0790-03

Steinmann, W., & Saelhoff, A.-K. (2016). Essential Properties of Fibres for Composite Applications. *Fibrous and Textile Materials for Composite Applications*, 39-73.

Zini, E., & Scandola M. (2011). Green composites: An overview. *Polymer Composites*, *32*(12), 1905-1915. doi.org/10.1002/pc.21224

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