



Determination of Physiochemical and Mechanical Properties of Composite Panels Produced from *Grewia mollis* Root Fiber/Polyester

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Abstract

*These days, a lot of researchers are working in the field of polymer composites containing natural fibers to develop either fully or partially biodegradable green composite due to increasing concerns about the environment. This study determined the physiochemical and mechanical properties of composite panels produced from *Grewia mollis* (GM) root fibre/polyester. Experimental research design was adopted for the study. The *Grewia mollis* root fibre was extracted and chemically processed by retting, scouring, bleaching, and mercerizing respectively. The traditional hand lay-up method was applied in producing the composite panels and their physiochemical and mechanical properties were determined according to ASTM standards. Descriptive statistics of percentage (%) scatter plot and bar charts were used to analyze and present the data. The result revealed that oil absorption increases while water absorption decreases as the concentration of NaOH increases and static with time. This implies that the untreated fibre-reinforced composites absorb more water than oil whereas the treated fibre-reinforced composites absorb more oil than water. The mechanical properties of the treated fibre-reinforced composites were improved significantly as the concentrations of NaOH increases up to a threshold point of 15% before experiencing a decrease from threshold points of 20-25%. This shows that composites treated with 5–15% NaOH gave better improvements than 20–25% and the maximum improvements were found for 15% NaOH. Therefore, on the basis of % NaOH, threshold point of 15% possessed the ideal combination of mechanical qualities. The outcome shown that the treated fiber-reinforced composites might be used as an alternative to other naturally fiber-based products since they offered better physiochemical and mechanical qualities than the untreated fiber-reinforced composites. According to the study, appropriately adjusting these processing parameters may result in a more effective or practical composite panel solution for our home and commercial uses, including the furniture, automobile, and construction industries, among others.*

Keywords: *Grewia mollis*, Reinforcement, Polyester, Composite Panels, Fibre.

Introduction

There has been increased interest in the development of composite materials with relevant physicochemical, chemical and mechanical properties for use in domestic and industrial applications in the last two decades. This constant development of natural fibre-reinforced polymer composites has impacted life and the nature of jobs in all fields of science and technology. Polymer science and technology as the main vehicle for human resources development needs to heed to the constant development of natural fibre-reinforced polymer composites. When compared to synthetic fibers, natural fibers are thought to be among the more beneficial to the environment because of their superior qualities¹. Sustainability and eco-friendliness are the main current criteria for manufacturing products².

In line with this, composite materials including naturally sourced fibres, therefore, are suitable to fulfilling the green

requirements for producing eco-friendly products with interesting physicochemical and mechanical properties^{3,4}.

However, the non-biodegradability and high cost of commonly used composite materials, such as glass and carbon-reinforced polymeric material, limit their sustainability^{2,5}. Given these limitations, low-cost natural fibres have been introduced as alternative to the existing synthetic fibres in composite material formulation because they have sufficient mechanical qualities, are low in density, and are well biodegradable². This rapid development in the usage of low-cost natural fibres in composite requires the current generation of polymer scientists to wide their searches or knowledge and skills for them to face the tasks in the world of polymer technology. Polymer engineering is becoming the way of life in this increasingly global economy, it is therefore imperative for the polymer scientists to be fully prepared to live in the world of polymer engineering.

The problem faced by manufacturers is the selection of natural fibre which is the most important process for polymer composites with comparable or better physicochemical, mechanical, and other functional properties⁶. *Grewia mollis* (GM) fibre has been reported to be utilized in composites, majorly because of its availability and cost efficiency⁷. In the current study, its root fibre was selected as reinforcement material for polyethylene terephthalate composite formulation. This research aimed at extracting cellulose fibre from *Grewia mollis* (GM) root and developing composite panels from the extracted GM root fibre/waste FARO water bottles (polyethylene terephthalate) with the view to reducing waste disposal in our environment and to reveal the trend of alkali treatment on the mechanical properties of the produced composite panels and justifies their optimum alkali treatment. The identification of certain mechanical, physiochemical and other features of the created composite panels, which, if appropriate would be suggested for use in the furniture, building and related industries.

Materials and Methods

The used FARO water bottles were gathered from different parts of Yola, which is a city in Adamawa State, Nigeria, located at latitude 9.280 and longitude 12.480.

Methods: Sample Preparation: The waste bottles were cut into smaller pieces to foster the dissolution in solvent (Figure-1). *Grewia mollis* root fibre was used as reinforcement material which was collected from Bagale Mountain located at Girie Local Government Area of Adamawa State, Nigeria. The fibre was extracted and chemically processed by retting, scouring, bleaching, and mercerizing processes respectively (Figure-2). These were done according to the standard methods adopted by John et al⁸. The retting process involved the subjection of the fibre with 5% NaOH for 4 hours, this was followed by scouring which involved treatment of the fibre with 2% sodium hydroxide to remove all impurities by oxidation. The fibre becomes cleaner, stronger, and more absorbent. The fibre was bleached with 5% hydrogen peroxide at 100⁰C for 1 hour in the water bath, to remove all-natural colouring matter by oxidation. The fibre was then mercerized with 5-25% sodium hydroxide to justify the optimum alkali treatment for the composite and dried under the sun, natural air and oven to remove the free water and later stored in an air tight container after cutting into smaller pieces. By melting phenol in an oil bath at 450C, the solvent for dissolving polyethylene terephthalate was prepared and mixing it with liquid 1, 1, 2, 2-tetrachloroethane in the ratio 60/40 w/w as described by Dass and John et al^{8,9}.

Preparation of Waste PET Solution: In a beaker filled with phenol-1, 1, 2, 2-tetrachloroethane solution, the crushed polyethylene terephthalate was added and heated to 100 0C. The mixture was agitated until all of the PET was dissolved, producing a thick liquid as reported by John et. al⁸.

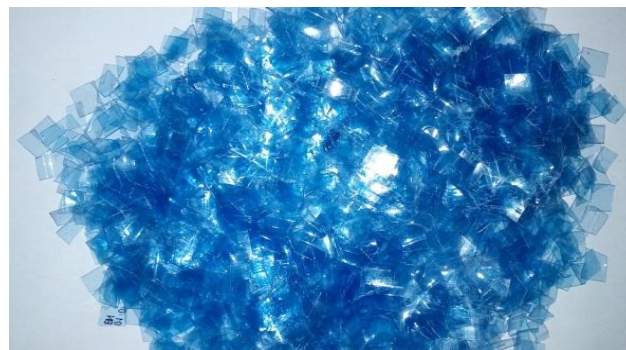


Figure-1: Pulverized PET particles.



Figure-2: *Grewia mollis* root fibre.

Formulation of GM Fiber/Polyester Composite Panels: The composite panels were formulated using the standard procedure described and adopted by John and Usman et. al^{8,10}. An aluminium mould was prepared and de-bonding substance was first introduced on the inner area of the mould followed by a pigmented gel coat to give high quality surface finish. 20 g of the crushed fibre was manually laid in the mild randomly and the melted polyethylene terephthalate (polyester) was poured and casted into the mould. The prepared composite materials were allowed to air dry to a structural panel for 1 hour at ambient temperature. They were then extracted from the mould, labelled and stored at room temperature in an open space in the laboratory for further use (Figure-3).



Figure-3: Formulated GM fibre/polyester composite panels.

Characterization of Fibre Plastic Composites: Water Absorption Test (ASTM D570): The composite materials were divided into 20x10x3 (length x width x thickness) mm³ pieces, and they were let to soak for up to 168 hours at 25⁰C in a stable water bath. Weighing the specimen both before and after it was submerged in water allowed us to calculate how much water it had absorbed.

The equation provided by John and Usman et al^{8,10} was used to calculate the proportion of water that was absorbed as shown below:

$$\text{Absorption (\%)} = \frac{\text{Final weight} - \text{initial weight} \times 100}{\text{Final weight}} \quad (1)$$

Oil Absorption Test (ASTM Oil No. 3): The test employed using engine oil as medium, the standard testing method described by Munoz and Garcia-Manrique 11 and adopted by John et. al⁸ was employed. The composite specimens were cut into 20x10x3 (length x width x thickness) mm³ and immersed in a stable oil bath at 25⁰C for different time intervals (up to 168 hours). Weighing the specimen both before and after it was submerged in engine oil allowed us to calculate how much oil was absorbed. The same equation used for the water absorption test was utilized to determine the engine oil absorption percentage.

Tensile Strength Test (ASTM D638-99): Using an Enerpac Universal Hydraulic Digital Material Testing Machine (model: H50KS-0404, Hounsfield Series S, UK) with a cross-head speed of 10 mm/min and a span distance of 50 mm, the test was carried out in accordance with ASTM D638-99. The composite samples were cut with dimensions of thickness (t) of 3 mm and width (b) of 15 mm and mounted on the machine and the tensile force were noted and recorded. The tensile stresses of the composite materials were determined using the formula below:

$$\partial_t = \frac{p}{A} \quad (2)$$

Where: ∂_t = Tensile stress of the composite sample (MPa), p = Applied load (N), A = Width * thickness of composite sample (mm)^{8,10}

Flexural Strength Test (ASTM D790-99): The test was performed according to ASTM D790-99 8 using the same testing machine used for the tensile test with a cross-head speed of 60 mm/min at a span distance of 25 mm. The composite materials were cut into cuboid shapes and mounted on the machine with supports at both ends and compressed at the middle in opposite direction to the supports. The load was applied on the composite samples until failure occurs and the load was noted and recorded as well. The flexural stresses of the composite materials were determined using the formula as shown below:

$$\partial_f = \frac{3pL}{2wt^2} \quad (3)$$

Where: ∂_f =flexural stress of the composite sample (MPa), p = load (N), L = support span (mm), w = width of the composite sample (mm), t = thickness of the composite sample (mm).

Results and Discussion

Discussion: Effect of Water Absorption on GM fibre/polyester composite: The effect of water absorption on GM fibre/polyester composites against time was studied. The properties of untreated GM fibre/polyester composites were obtained along with that of the treated ones. The result obtained shown that the absorption rate was very high at first 24 hours and steadily increased up to 96 hours. An apparent equilibrium was attained at 96–168 hours of soaking time as there was no significant variation in percentage absorption within these periods for both the untreated and the treated composites.

The absorption rate for the treated composites was far lower than that of the untreated ones as depicted in Figure-4. These observations agree with the investigations of Azwin and Nih, John and Usman et. al^{8,10,12}. The higher absorption rate shown by the untreated polyester composites could be due to the present of strongly polarized hydroxyl groups in natural fibre causing smooth interaction between the fibre and the water molecules. Thus, when subjected into water, it absorbed some volumes of water for first hours than the treated fibres^{13,14}. The lower absorption rate for the treated polyester composites could be due to excessive extraction of lignin content of the fibre as the concentration of NaOH increases progressively with time, which at higher concentration may result in damaging the ultimate cell walls of the fibre and subsequently reducing the absorption capacities of the fibre and thereby strengthening the interfacial bonding between the polymer matrix and the fibre, leading to a considerable improvements in the mechanical properties of the composites with higher concentration of sodium hydroxide^{8,10,15,16}.

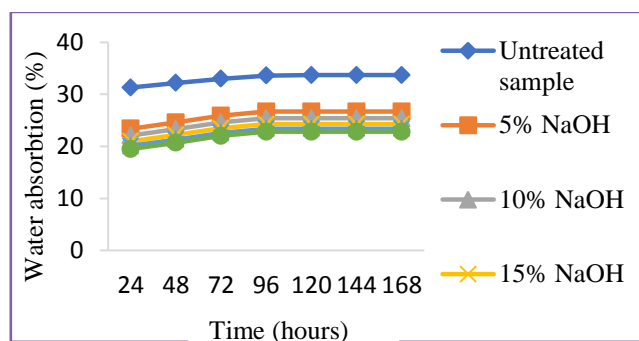


Figure-4: Effect of water absorption on GM fibre/polyester composite.

This also account for an extremely slow increase in absorption rate with time for both the composites treated with 20 and 25% NaOH. Therefore, the composite treated with 5% has the highest water absorption and the composite treated with 25% has the lowest. This demonstrates that when NaOH concentration rises, water absorption falls. This indicates that there is a direct relationship between the absorption rate and the NaOH content. According to reports, mercerization tends to reduce absorption of water¹⁵.

Effect of Oil Absorption on GM fibre/polyester composite:

The effect of engine oil uptake (%) for the untreated and the treated GM fibre/polyester composites up to 168 hours of soaking time was also studied. The absorption rate was low at first 24 hours and then it slightly increased till 72 hours. After 168 hours of soaking time, the absorption rate was same. An apparent equilibrium was attained at 96–168 hours of soaking time as there was no significant variation in percentage absorption within these periods for both the untreated and the treated composites as depicted in Figure-5.

This shows that the composites reached their maximum saturation points at these periods. The percentage absorption increases progressively as the concentration of NaOH increases. This implies that treated composites absorb more oil than the untreated ones. This is because natural organic material from plants and fruits shows low oil absorption ability due to their oleophobicity properties^{17–19}. These observations agree with the work of^{10,12}. The absorption of water is higher than that of the engine oil as depicted in Figure-5. This is because the density of water is lighter than engine oil²⁰. For the untreated composites, there was an initial rapid increase in water absorption and initial slow increase in oil absorption. For the treated composites, there was a slow increase in water absorption and initial rapid increase in oil absorption which is directly proportional to the concentration of NaOH.

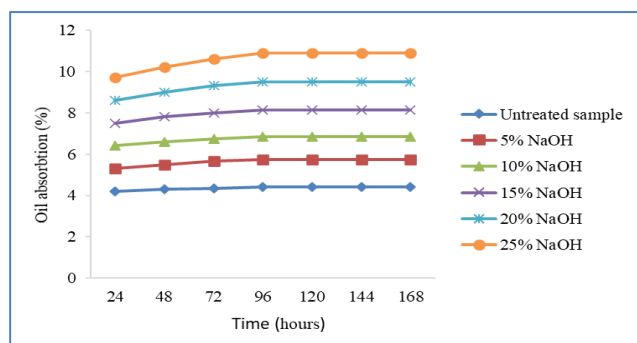


Figure-5: Effect of oil absorption on GM fibre/polyester composite.

Effect of Tensile strength (TS) on GM fibre/polyester composite:

The effect of GM fibre composites on the TS as the concentration of NaOH varies was studied. The result showed that TS increases as the concentration or percentage (%) of NaOH increases up to a threshold point of 15% and then experienced a decrease from 20–25% as observed in this work and as reported by Usman and John et. al^{8,10}. This implies that composites treated with 5–15% gave better results than those treated with 20–25% as depicted in Figure-6. This is because at low (%), the GM fibre is highly compacted by the polyester and there is little or no fibre touching one another and that higher (%), above 15% will damage its cell wall resulting in low bonding between the fibre and the matrix leading to subsequent reduction in the mechanical properties of the composite¹⁵.

There is slight difference in the trend as 15% emerges as the best with tensile value of 44.05 MPa compared to untreated fibre reinforced polyester matrix with tensile value of 32.85 MPa. Therefore, on the basis of % NaOH, threshold point of 15% had the optimum set of mechanical properties. This result agrees with the investigations of Akter, John and Usman et. al^{8,10,13}. This may be due to the fact that natural fibres are characterized by high water uptake and this phenomenon decreases the adhesive characteristics of fibre surface and weakens the interfacial bonding between the polymer matrix and the fibre thereby deteriorating the tensile strength of the composites as reported by Al-Mosawi and Ali¹⁵.

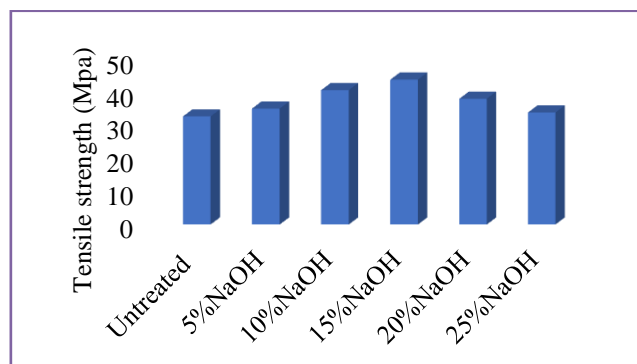


Figure-6: Tensile strength variation of GM fibre/polyester composite with concentration.

Effect of Flexural strength (FS) on GM fibre/polyester composite:

The result showed that FS increases progressively as the concentration or percentage (%) of NaOH increases, which is more pronounced at 15–25% NaOH as observed in this work and as reported by Al-Mosawi and Ali, John and Usman et. al^{8,10,15}. The composite treated with 25% has the highest FS whereas the composite treated with 5% has the least as depicted in Figure-7.

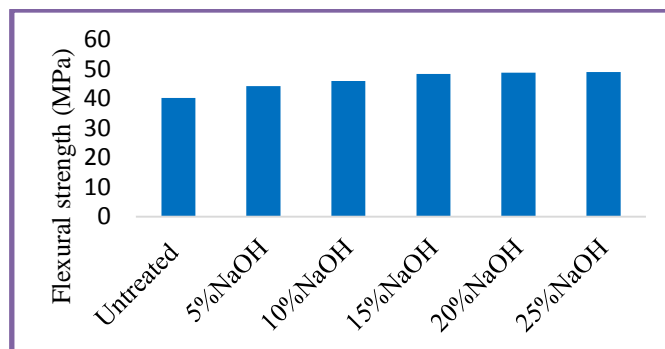


Figure-7: Flexural strength variation of GM fibre/polyester composite with concentration.

Similarly, as the concentration of NaOH increases, cross linking between the resin and the fibre may be enhanced. This may be because alkali treatment hydrolyzes the amorphous cellulose found in natural fibers, increasing the amount of crystalline cellulose in the treated material²¹.

According to John et al.¹⁰, the higher starting modulus of the natural fibers serving as the composites' backbones is thought to be the cause of the improvement in flexural modulus. In the present research, high flexural strength was observed in treated GM fibre composites as compared to the untreated GM fibre composites. The reason could be in alkali treated fibre, the lignin and hemicellulose content are removed leading to proper bonding between the fibre and the polymer matrix as reported by Al-Mosawi and Ali, John et al. and Xue et al.^{8,10,22}.

Conclusion

The retting, scouring, bleaching and mercerizing the GM fibre with sodium hydroxide (NaOH) and hydrogen peroxide (H₂O₂) proved to be suitable and reliable because the surfaces of the treated GM fibre samples and the physical and mechanical changes observed on them were in total agreement with the theories of retting, scouring, bleaching and mercerization processes. The suitability and reliability of these retting, scouring, bleaching and mercerizing agents were confirmed by the improved physiochemical and mechanical properties shown by the treated GM fibre samples as compared to the untreated GM fibre samples. This shows that NaOH and H₂O₂ are useful agents for retting, scouring, bleaching and mercerizing cellulose materials.

The results obtained from the physiochemical and mechanical tests showed that the absorption of water is higher than that of the engine oil and that the untreated fibre reinforced composites absorb more water while the treated ones absorb more oil. This proved that the density of water is lighter than engine oil and natural fibres are hydrophilic not oleophilic. The treated composites recorded higher tensile and flexural values than the untreated ones. This implies that the treated fibre reinforced composites will be sensitive to a wide range of applications where high tensile and flexural strengths variations are required. Addition of NaOH in the composites significantly improved the mechanical attributes of the composites and the optimum improvements were found for 15%. This implies that the composites treated with higher concentration of NaOH present better resistance to water and show good mechanical properties than those treated with lower concentration of NaOH and that higher percentage of NaOH, above 15% will damage their cell wall and subsequently reducing their mechanical properties. All these variations in mechanical properties are due to differences in the chemical composition of the composites.

This finding clearly showed that the produced composites present better physiochemical and mechanical properties and could be used as an alternative to other commercial natural fibre products. This conclusion is supported by previous researches that alkali treated fibre reinforced polymer composites offered superior physiochemical and mechanical properties than the untreated fibre reinforced polymer composites. This shows that the potential application of *Grewia mollis* based composites in domestic and industry are going to increase in near future.

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