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Investigation Of The Potential Application Of *Grewia Mollis* Root Fiber Reinforced Polyester Composite In Panel Board Production

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ABSTRACT

The main objective of this study is to investigate the effect of Grewia mollis root fibre as a reinforcement material for polyester composites in panel board production. The composite was produced using hand lay-up technique and its physiochemical and mechanical properties were studied according to American Society for Testing and Materials (ASTM) standards. It was observed that the 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% had the optimum set of mechanical properties. The results showed that the treated fibre-reinforced composites offered superior physiochemical and mechanical properties as compared to untreated fibre-reinforced composites and could be used as an alternative to other commercial natural fibre products. The fibre was extracted and chemically processed by retting, scouring, bleaching, and mercerizing respectively. The proper optimization of these processing parameters can be a better or viable solution of this composite for our domestic and industrial applications such as automotive, construction, furniture etc.
Keywords: Application, *Grewia mollis*, Reinforcement, Polyester, Composite, Panel board, Production.

INTRODUCTION

Nowadays, growing environmental concerns have led many researchers to work in the area of natural fibre reinforced polymer composites to develop either fully or partially biodegradable green composite. However, 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. Natural fibres are considered one of the environmentally friendly materials which have good properties compared to synthetic fibres (May Pat *et al.,* 2013). Sustainability and eco-friendliness are the main current criteria for manufacturing products (Yahya *et al.,* 2017). 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 (Sanyang *et al.,* 2017 and Ilyas *et al.,* 2019). However, commonly applied composite materials, including glass and carbon-reinforced polymer, are non-biodegradable and costly, limiting their sustainability (Yahya *et al.*, 2017 and D'Urso *et al.*, 2018). Given these limitations, low-cost natural fibres have been introduced as alternative to the existing synthetic fibres in composite material formulation because they offer good biodegradability, low density, and they have adequate mechanical properties (Ilyas *et al.,* 2018). 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 science and 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.

Statement of the Problem

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 properties (Lokantara *et al.,* 2020). *Grewia mollis* (GM) fibre has been reported to be utilized in composites, majorly because of its availability and cost efficiency (Abdullahi, 2017). Previous research on it stem fibre has revealed its good mechanical properties and other properties such as good specific strengths, modulus, light weight, and finally economic viability (Abdullahi, 2017). But, no report has been found on the potential application of it root fibre, in composite fabrications. In the current study, its root fibre was selected as reinforcement material for polyethylene terephthalate composite formulation.

Purpose of the Study

This research aimed at extracting cellulose fibre from *Grewia mollis* (GM) root and developing a composite panel from the extracted GM root fibre/waste FARO water bottles (polyethylene terephthalate) with the view to reducing waste disposal in our environment and testing of some physiochemical and mechanical properties of the developed composites which if suitable would be recommended for used in automotive, construction, furniture and allied industries. Also, to reveal the trend of alkali treatment on the mechanical properties of the produced composites and justifies their optimum alkali treatment.

Scope of the Study

This research work is limited to the production of composite panels using *Grewia mollis* root fibre/waste FARO water bottles and determination of some physiochemical and mechanical properties of the produced composites as well as suggesting some possible areas of their applications.

Significance of the Study

The findings of this study will help in the following ways:

i. Reveal the trend of alkali treatment on the mechanical properties of natural fibre reinforced polymer composites and justifies their optimum alkali treatment.
ii. Provide cheaper, readily available reinforcing material and high quality polymer composites with good optimum alkali treatment, making them especially ideal for domestic and industrial production.
iii. Provide job opportunity, since, it is labor intensive.
iv. Support the recyclability of waste and contaminated plastics as well as the characteristic of fibre composites which consequently encourage the development of natural fibre-reinforced plastics.
v. Leads to the expansion in the interest for the commercial utilization of natural fibre-reinforced plastics in different industrial sectors.
vi. Minimize the release of harmful substances to the environment, thereby reducing the potential adverse health effect related to the production and uses of synthetic fibre.

LITERATURE REVIEW

In recent years various modifications were introduced in the natural fibre composites which increased their capability (Usman, 2023). Many researchers have conducted research on natural fibre as an alternative to synthetic fibres by improving the physical and mechanical properties of composite materials (Thakur et al., 2010). Improvement in properties such as impact toughness and fatigue strength can be seen with the use of chemically treated natural fibres (Usman, 2023). Recent review on the natural fibre composites highlighted the trends in the research and development on natural fibre reinforced polymer composites (NFRPCs) and its performance. The review covers current research efforts on the NFRPCs fabrication, its properties such as mechanical strength, tribological, water, and chemical resistance behavior, thermal effects, biodegradability and machining characteristics (Vigneshwaran *et al.,* 2020).

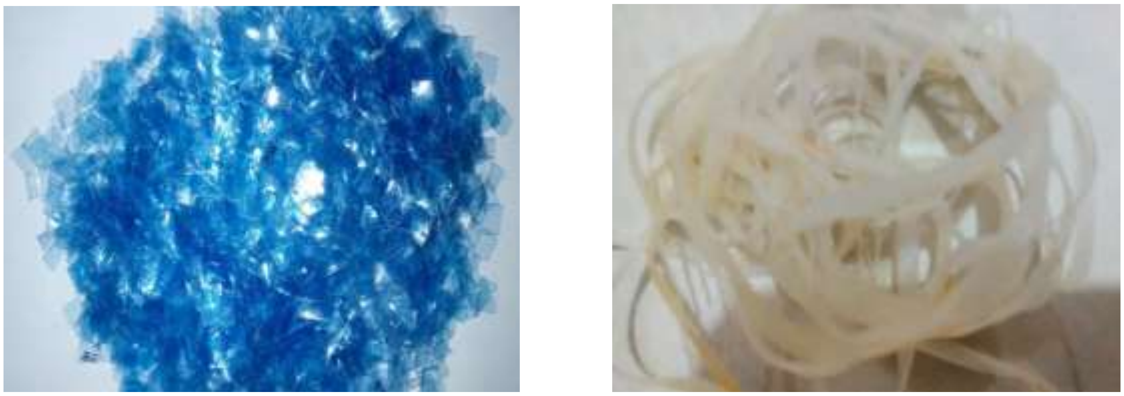
A number of innovative works have been reported on the use of natural fibres to improve the mechanical properties of polymer composites (Kim *et al.,* 2013 and Singh *et al.,* 2015). Many investigations conducted by many researchers on the influence of various type of chemical treatment showed significant improvements on the physical and mechanical properties of natural fibre reinforced polymer composites (Abdullahi, 2017; IIyas *et al*., 2018 and Prakash and Viswanthan, 2019). Gomes *et al*. (2007) formulated corn starch based curaua fibre green composites and reported that the tensile strength of the alkali-treated fibre composites increased in fracture strain two to three times more than untreated fibre composites. Huda *et al*. (2007) developed the kenaf fiber/PLA based composites and found that both silane-treated fiber reinforced composite and alkali treated fiber reinforced composite offered superior mechanical properties as compared to untreated fiber reinforced composites. Masoodi and Pillai (2012) studied the moisture and swelling behavior in bio-based jute-epoxy composites and found that moisture diffusion rate into the composites increased with increase in jute-fiber-to-epoxy ratio. Also water absorption and swelling were higher in bio-epoxy parts compared to the epoxy parts. Dass *et al.* (2016) studied water absorption, flammability, hardness and morphology tests on composite prepared from high density polyethylene films/doka wood dust particles. It was found that the water absorption increases as Doka wood particles increased but decreases as the high density polyethylene films increased. Abdullahi (2017) investigate the potential application of some natural fibres as reinforcement for polyester composite. The results obtained indicate that the mechanical properties and the densities of the treated polyester composites increase while moisture absorption decreases as the concentration of the alkali increases. Ahad, *et al.* (2018) describes the oils and water absorption behavior of natural fibres filled TPU composites for biomedical applications. It was observed that the overall, absorption of water and oil increased its percentage when the filler content in the composites increases. The composites with fibre from rambutan, pineapple and banana skin absorb more water and the composites filled with pineapple and rambutan absorb more engine oil, as well as cooking oil. Das *et al.* (2018) studied the effect of fibre loading on the mechanical properties of jute fibre reinforced polypropylene composites. It was found that the water absorption rate was higher and then it became slower and static with time and the mechanical properties of the composites increased with the increase in jute fibre content up to 50% by weight; however, further increase in fibre loading the value decreased. Akinterinwa *et al.* (2020) carried out a preliminary evaluation of composite panels produced from rice husk and recycled polystyrene material. Results showed that: dry time and density increased, water absorption and thickness swelling decreased while flammability increased (ignition time decreased and propagation rate increased), as the amount of the recycled polystyrene binder was increased in the composites. A number of methods for recycling waste polyethylene terephthalate have been established to reduce environmental pollution and reliance on fossil resources; these include methanolysis (Genta *et al*., 2005), glycolysis (Laldinpuii *et al*., 2021), neutral hydrolysis (Colnik *et al*., 2021), alkaline hydrolysis (Ugduler *et al*., 2021) and acidic hydrolysis (Peng *et al*., 2023). Among which chemical recycling appear to be the only acceptable method according to the principles of sustainable development (Grigore, 2017 and Peng *et al*., 2023). This method was also employed in the current research work using phenol-1, 1, 2, 2-tetrachloroethane which successfully dissolved the waste polyethylene terephthalate at a temperature of about 100 ^{0}C. This solvent was reported to be used in dissolving polyethylene terephthalate in a number of researches. Dass *et al.* (2018)

formulated PET waste bottles (FARO)/tea leaves waste fibres composite and found that modulus of rapture, flammability, and hardness increases with increased in the amount of PET and decreases with increased in the amount of fibre while water absorption decreases with increased in the amount of PET and increases with increased in the amount of fibre. Rukundo (2019) also produced a composite from waste PET/waste tea leaves fibre. The result showed that increased in the amount of PET increases modulus of rapture, flammability, and hardness and increased in the amount of fibre increases water absorption and vice-versa.

MATERIALS AND METHODS

Collection and preparation of raw materials

Polyester resin was used as a matrix material which was synthesized from waste FARO water bottles (recycled polyethylene terephthalate). The waste FARO water bottles were collected from various location of Yola metropolis located at latitude 9.28 and longitude 12.48, Yola Local Government Area of Adamawa State, Nigeria. The bottles were crushed into smaller pieces to facilitate dissolution in solvent. *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. These were done according to the standard methods adopted by Abdullahi (2017) and Usman (2023). The retting process involved the treatment of the fibre with 5% sodium hydroxide for 4 hours, and then 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 100 ^{0}C 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. The solvent for the dissolution of polyethylene terephthalate was prepared by melting phenol in oil bath set at 45 ^{0}C and mixing it with liquid 1, 1, 2, 2-tetrachloroethane in the ratio 60/40 w/w as described by Dass *et al*. (2018); Rukundo (2019) and Usman (2023).



(a) **(b)**

Fig. 1: Pulverized PET particles (a) and *Grewia mollis* root fibre (b)

Preparation of Liquid Polyethylene Terephthalate

The pulverized polyethylene terephthalate were added to phenol-1, 1, 2, 2-tetrachloroethane solution in a beaker (Fig. 2) and heated at 100 ^{0}C. The mixture was stirred until PET dissolved completely forming a viscous solution as reported by Rukundo (2019) and Usman (2023).

Fig. 2: Polyethylene terephthalate solution

Formulation of GM Fiber/Polyester Composite Panels

The composite panels were formulated using the standard procedure described by Abdullahi (2017) and adopted by Usman (2023). An aluminum mold was prepared and de-bonding agent was first applied on the inner surface of the mold followed by a pigmented gel coat to give high quality surface finish. 20 g of the crushed fibre was manually laid in the mold randomly and the melted polyethylene terephthalate (polyester) was poured and casted into the mold. The prepared composite materials were allowed to air dry to a structural panel for 1 hour at room temperature. They were then removed from the mold, labeled and stored at room temperature in an open space in the laboratory for further use.

Fig. 3: Formulated GM fibre/polyester composite panels

Characterization of Fibre Plastic Composites

Water Absorption Test (ASTM D570)

The composite materials were cut into 20 x 10 x 3 (length x width x thickness) mm^3 and soaked in a static water bath at 25 ^{0}C for various periods of time (up to 168 hours). The amount of water absorbed was measured by weighing the specimen before and after immersion in water. The absorption percentage of water was measured using the Equation described by Ahad *et al.* (2018) and used by Usman (2023) as shown below;

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

Oil Absorption Test (ASTM Oil No. 3)

The test was using engine oil as the medium and the standard testing method adopted by Munoz and Garcia-Manrique (2015) was employed. The composite specimens were cut into 20 x 10 x 3 (length x width x thickness) mm^3 and soaked in a static oil bath at 25 ^0C for various periods of time (up to 168 hours). The amount of engine oil absorbed was measured by weighing the specimen before and after immersion in engine oil. The absorption percentage of engine oil was calculated using the same Equation used for the water absorption test.

Tensile Strength Test (ASTM D638-99)

The test was performed according to ASTM D638-99 using the enerpac Universal Hydraulic Digital Material Testing Machine (model: H50KS-0404, Hounsfield Series S, UK) with a cross-head speed of 10 mm/min at a span distance of 50 mm. 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 adopted by Abdullahi (2017) and used by Usman (2023) as shown below;

$\sigma_t = p/A$

But $A = b \times t$, $\sigma_t = p/b \times t$

Where;

σ_t = tensile stress of the composite sample (MPa)
p = load applied (N)

b = width of the composite sample (mm)

t = thickness of the composite sample (mm).

Flexural Strength Test (ASTM D790-99)

The test was performed according to ASTM D790-99 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 adopted by Abdullahi (2017) and used by Usman (2023) as shown below;

$\sigma_f = 3PL/2wt^2$

Where;

σ_f = flexural stress of the composite sample (MPa)
P = load at a given point on the load deflection curve (N)

L= support span (mm)

w = width of the composite sample (mm)

t = thickness of the composite sample (mm).

RESULTS AND DISCUSSION

Water Absorption Test (WAT)

Figure 4 depicts the effect of water absorption on GM fibre/polyester composites against time in hours. 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 below.

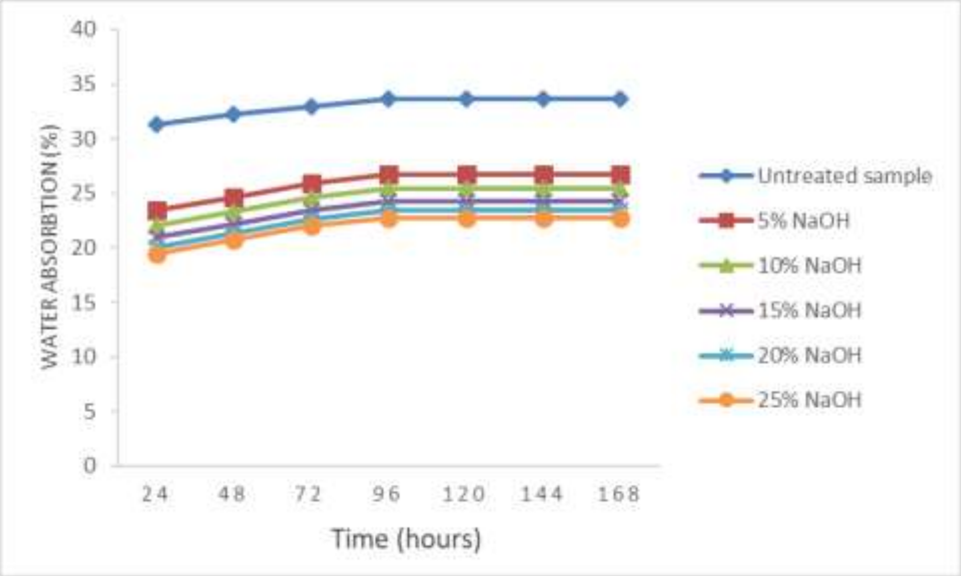


Fig. 4: Effect of water absorption on GM fibre/polyester composites against time in hours.

These observations agree with the work of Ahad *et al*. (2018). 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. Hence, when immersed into water, it absorbs huge amount of water within first hours than the treated fibres (Saha *et al.*, 2016 and Akter *et al.*, 2018). 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 (Al-Mosawi, 2012; Abdullahi, 2017; IIyas *et al*., 2018 and Prakask and Viswanthan, 2019).

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 shows that water absorption decreases as the concentration of NaOH increases. This means that the absorption rate is directly proportional to the concentration of NaOH. As reported, mercerization tends to decrease water absorption (Al-Mosawi, 2012).

Oil Absorption Test (OAT)

Figure 5 shows the effect of engine oil uptake (%) for the untreated and the treated GM fibre/polyester composites up to 168 hours of soaking time. 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 below.

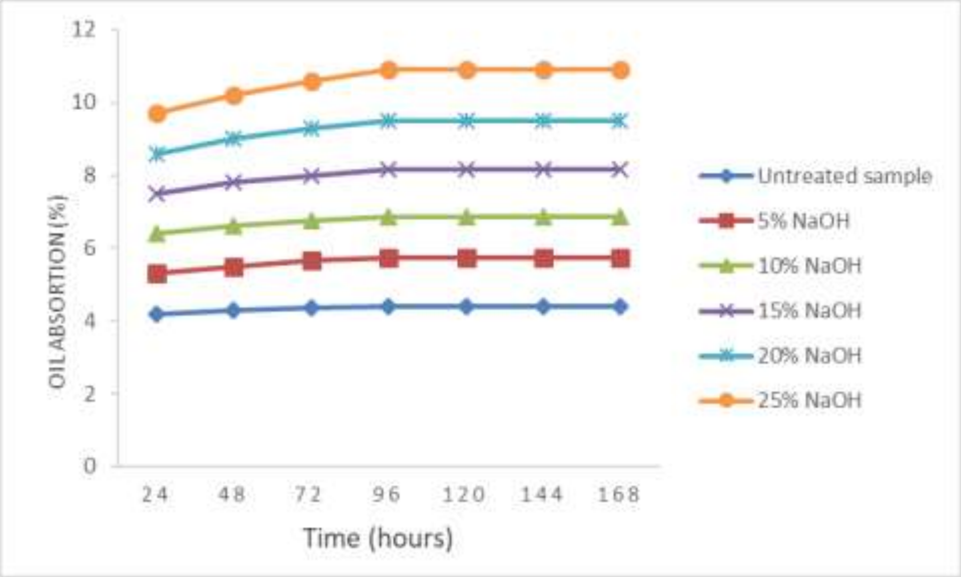


Fig. 5: Effect of oil absorption on GM fibre/polyester composites against time in hours.

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 show low oil absorption ability due to their oleophobicity properties (Nguyen *et al.*, 2013; Marko *et al.*, 2013 and Jorda *et al.*, 2017). These observations agree with the work of Ahad *et al*. (2018). The absorption of water is higher than that of the engine oil as depicted in Figure 4 and 5 respectively. This is because the density of water is lighter than engine oil (Dong *et al.*, 2015). 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.

Tensile Strength Test (TST)

Figure 6 represents the effect of GM fibre composites on the tensile strength (TS) as the concentration of NaOH varies. 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 Abdullahi (2017). This implies that composites treated with 5–15% gave better results than those treated with 20–25% as depicted in Figure 6 below.

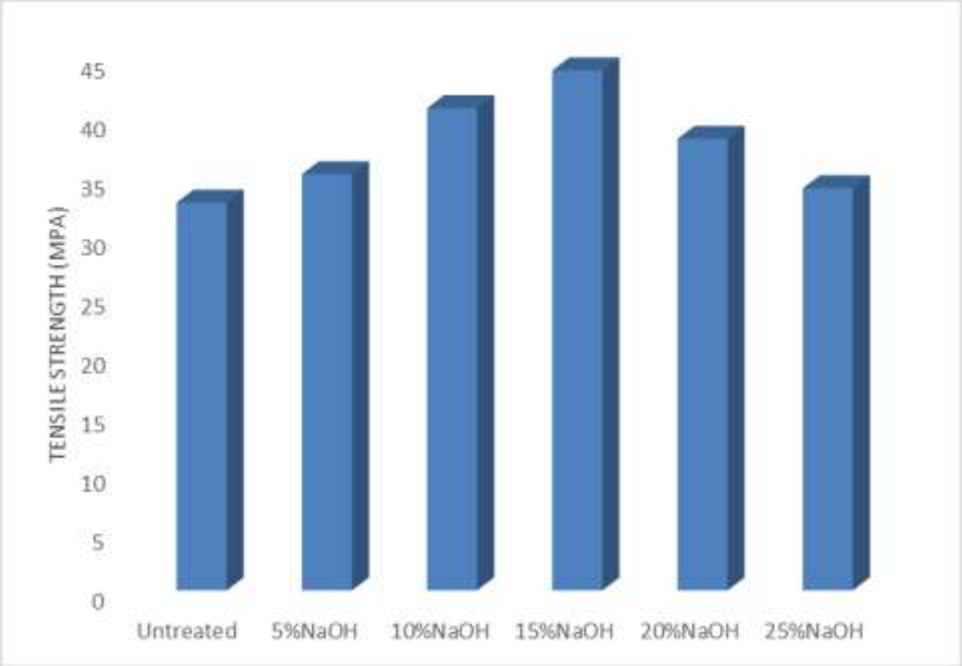


Fig.6: Variation in tensile strength of GM fibre composites as the concentration of NaOH varies.

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 subsequence reduction in the mechanical properties of the composite (Al-Mosawi, 2012). 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 work of Abdullahi (2017). 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, 2012).

Flexural Strength Test (FST)

Figure 7 depicts the effect of GM fibre composites on the flexural strength (FS) as the concentration of NaOH varies. 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 Abdullahi (2017). The composite treated with 25% has the highest FS whereas the composite treated with 5% has the least as depicted in Figure 7 below.

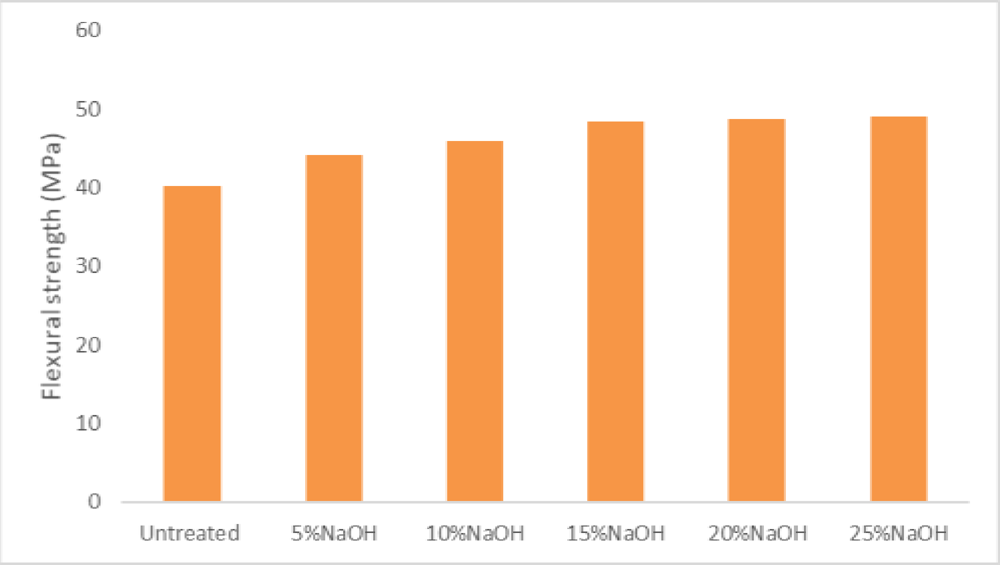


Fig. 7: Variation in flexural strength of GM fibre composites as the concentration of NaOH varies.

Similarly, as the concentration of NaOH increases, cross linking between the resin and the fibre may be enhanced. This could be as a result of the fact that alkali treatment hydrolyzes the amorphous parts of cellulose present in natural fibres so that after treatment the material contains more crystalline cellulose (Le Troedec *et al.*, 2008). The improvement in flexural modulus is believed to be due to the higher initial modulus of the natural fibres acting as backbones in the composites as reported by (Rao *et al.*, 2010). 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 is removed leading to proper bonding between the fibre and the polymer matrix as reported by Xue *et al.* (2009). This was also reported by Abdullahi (2017).

CONCLUSION

Retting, scouring, bleaching and mercerizing the GM fibre with sodium hydroxide (NaOH) and hydrogen peroxide (H_2O_2) 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 H_2O_2 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 properties of the composites and the maximum 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.

RECOMMENDATIONS

This study creates wide scope for future studies. It can be extended to newer composites using several other reinforcing phases and the resulting experimental findings can similarly be analyzed. There are wide scopes for future scholars to explore this area of research. These are;

i. The fibre should be reinforced with other polymer matrix so as to ascertain the advantage it may offer if any, over the polyester used for this study.
ii. Different chemical treatment on the *Grewia mollis* fibre and its composites should be fabricated in order to ascertain the best chemical treatments that will suite them and their effect should be studied as well.
iii. Many other aspects of this problem like effect of fibre crystalline content, size, shape, thickness of cell walls, orientation, loading pattern, weight fraction of this fibre and its respective composites require further investigation.
iv. FT-IR should be carried out to identify the functional groups present in the composite,
v. XRD should be performed to deduce whether the composite is crystalline or amorphous in nature,
vi. SEM should also be carried out to study the morphology of the composite,
vii. Thermal analysis (TGA-DTG-DSC) should also be conducted to determine the temperature at which the composite will undergo degradation.

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Conflict of interest

The authors declare no conflict of interest.

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