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Effect of Chemical Treatments on the Mechanical Properties of Grewia mollis Root Fibre Reinforced Waste Plastic Material Composites

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ABSTRACT

Reinforcing polymers with natural fibres has recently been the center of attention among many research groups around the globe. This study investigated the effect of chemical treatments on the mechanical properties of Grewia mollis root fibre-reinforced waste plastic material composites. The composites were prepared using hand layup technique and their moisture absorption and mechanical properties were investigated according to ASTM standards. The moisture absorption test revealed that moisture absorption behavior decreases as the concentration of NaOH increases. This implies that the untreated composites absorb more moisture owing to their hydrophilicity nature. This signifies that chemical treatments reduce moisture content of the green composites. The mechanical tests confirmed a mechanical improvement for the treated composites compared to the untreated ones. This shows that the untreated composites recorded low tensile and compressive values than the treated ones. The mechanical performance were considerably 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%. The chemical treatments results were correlated with the mechanical performance of the treated and untreated composites. The findings confirmed that the alkali treated composites offered superior mechanical properties as compared to the untreated composites and were found to be suitable for application into the allied industry.

Keywords: Characterization, Chemical treatments, Composite, Natural fibre, Reinforcement, Waste plastic material.

INTRODUCTION

Recently, the issues of global warming and environmental threats have been attracting a significant concentration [1]. These issues have encouraged researchers to seek for possible solutions and looking for alternative materials and green technology in many industrial sectors. The latter are relying on the production cost of composites and their functional applications such as transportation (automobiles, railway coaches, aerospace), building and construction industries (ceiling paneling, partition boards) and furniture packaging [2]. Green composites are produced using natural fibres derived from plants, which

consist of diverse chemical components including cellulose, hemicellulose, wax, and ash [3, 4]. Natural fibre composites (NFCs) are becoming increasingly attractive from both academia and industries for their diverse use in many applications. These materials possess unique properties such as improved specific strength, high modulus, biodegradability, eco-friendliness, eco-efficiency nature, low rate of carbon emission and ease of fabrication [5, 6].

Natural fillers that used to reinforce polymer matrices offer a new group of materials that provide notable mechanical characteristics with various applications [3, 7]. The sources of plant natural fibres are various parts of plants, including the bark, stems, leaves, and roots. The main commercially used cellulosic fibres consist of seed fibres (cotton, coir, kapok), bast fibres (flax, hemp, ramie, banana, bamboo), and leaf fibres (sisal, kenaf, abaca, pineapple). Root fibres (grewia mollis), and stem fibres such as grewia mollis, grewia ferruginea, jute, flax, hemp, kenaf, ramie, roselle, sun hemp, sacccharum, and banana are also utilized [8-11]. The mechanical performance of composites of natural fibres depends on many parameters such as the volume fraction of fibres, length, shape, arrangement, fibre polarity and the interfacial bonding with the polymer matrices [12]. Along with a number of benefits of natural fibres as reinforcements, there are some limitations on using natural fibres in composite preparation such as the lack of adequate adhesion between fibres and the matrix, hydrophilic nature as they contain strongly polarized hydroxyl group and poor thermal stability [1, 13].

Natural fibres are axiomatically incompatible with some of polymer matrices, such as polypropylene (PP) and polyvinyl chloride (PVC), as these matrices have hydrophobic nature. This shortcoming leads to weak interfacial bonding with polymer matrices which, as a result, lead to debonding of fibres and failure in the end use production [14]. The interface between reinforcing fibres and the matrix plays a critical role in determining the mechanical performance of green composite. Generally, the properties of natural fibre composites are unequivocally connected with the nature of the natural fibres and their compatibility with polymer matrices. Hence, it is very important to reduce the moisture absorption and hydrophobic character of natural fibres by making a proper surface treatment to enhance fibre compatibility with different resin matrices [15]. Several studies reported that chemical treatment to natural fibres improve the mechanical properties of the composites. There are a number of chemical treatments that can be used to improve the compatibility between matrix and fibre and increase the functionality of natural fibres. Alkali treatment is the most used chemical treatment for natural fibres to remove wax and oil covering some parts of these fibres and to increase the roughness of fibre surfaces that lead to better interlocking of fibres with the host polymer [14].

GU [16] used alkali treatment, NaOH solution, with concentrations varied from 2.0 to 10% separately on freshly brown laminated coir fibres to study their tensile behavior. He reported an improvement in coir fibre adhesion with polypropylene after the chemical treatment. He also reported a decrease in tensile strength values as the concentration of NaOH increased. One of the main conclusions was stated that as the concentration of NaOH is higher than 8%, the adhesion of the fibre with the matrix is improved. In similar procedure conducted by Karthikeyan and Balamurugan [17] NaOH was used for treating freshly retted long combed coir fibres. They made various concentrations (2.0, 4.0, 6.0, 8.0 and 10) % at ambient conditions for 10 days. The treated fibres were reinforced epoxy resin to study the mechanical properties. The treatment with 6% NaOH provided the best result in impact strength, while higher alkali concentrations reduced fibre strength and consequently the impact strength.

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 [11]. Several studies on the composites made from waste plastic matrix and natural fibres such as groundnut husk, wood dust particles, tea leaves waste and grewia mollis fibres were reported in the literature. Grewia mollis fibre (GMF) has been reported to be utilized in composites, majorly because of its availability, cost efficiency, good mechanical properties, and other properties such as good specific strengths, modulus, light weight, and finally economic viability [11]. But no report was found on the

effect of chemical treatments on the mechanical performance of this fibre in composite fabrication. This study investigated the effect of chemical treatments on the mechanical properties of *Grewia mollis* root fibre (GMRF) reinforced waste plastic material composites (WPMCs).

The major factors that affect the mechanical performance for the composites are the chemical treatment and the variation in physiochemical properties for the reinforcing materials. The mechanical performance represented by tensile and compressive strength and the physiochemical properties represented by moisture absorption for the untreated and the treated fibres and the composites were investigated and reported with a special focus on the failure mechanism. The main aim of this study is to design composite panels by selecting abundant WPMs (waste Faro water bottles) with the view to reduce waste disposal in our environment and adopting a cost effective approach of manufacturing as well as to investigate the effect of chemical treatments on the mechanical properties of the produced composites and justify their optimum alkali treatments which if found suitable would be recommended for application into the allied industry. The aforementioned investigation will possibly help in failure prediction approach for systems designed by employing these abundant WPMs.

MATERIALS AND METHODS:

Sample Collection

The waste Faro water bottles were gathered from Yola metropolis in Adamawa State, Nigeria (plate-1). *Grewia mollis* is a widespread species of flowering plant (plate-2) in the family Malvaceae, native to tropical Africa, Yemen, Oman, Senegal and Zimbabwe. It is also widely distributed in northern Nigeria especially north-eastern part of the country, locally known as (Dargaza in Hausa and Kelli in Fulfulde) and one of the medicinal herbs that is used traditionally to treat chronic diseases and related pain in northern Nigeria [18]. The GMRF was collected from Bagale Mountain located at Girie Local Government Area of Adamawa State, Nigeria (plate-3).



Plate 1: The waste FARO water bottles

Source: Self



Plate 2: The *Grewia mollis* plant
Source: Self

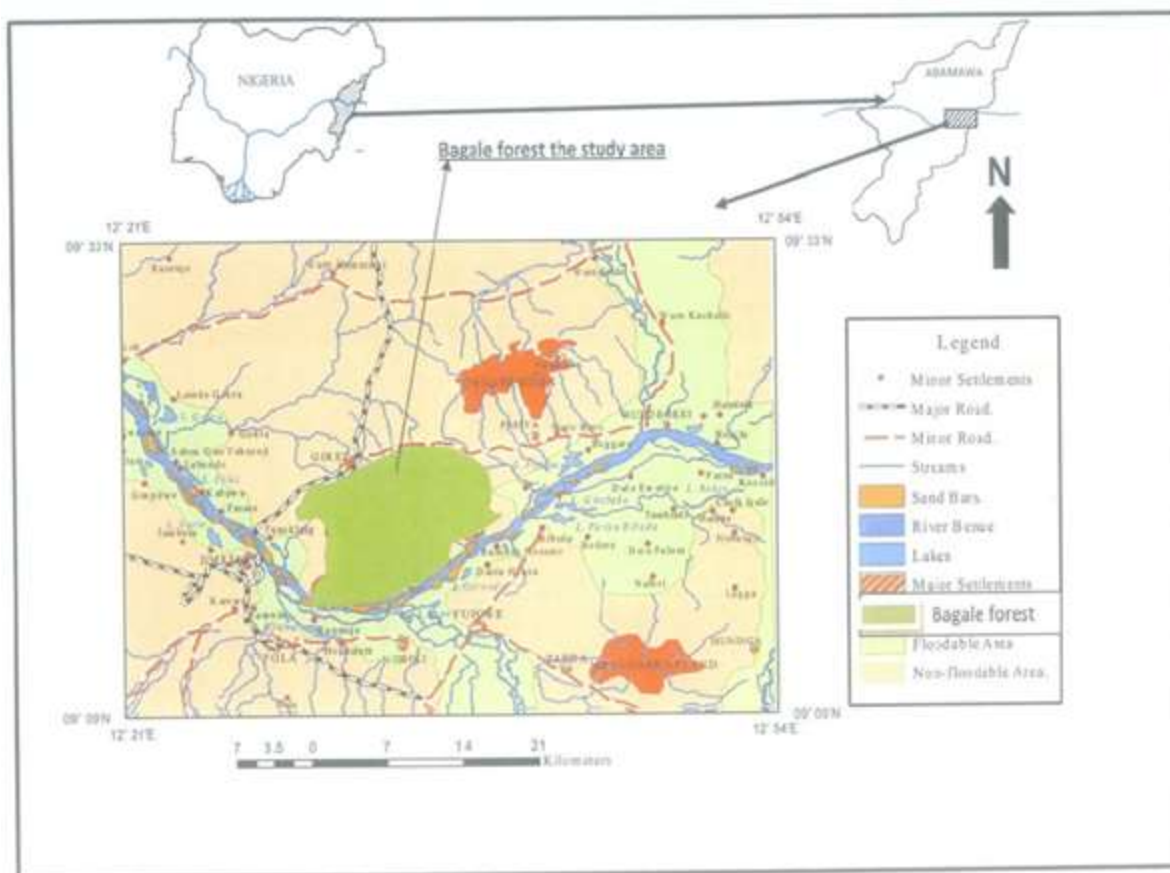


Plate 3: Map of Girei Local Government Area showing the Study Area

Source: [19]

Sample Preparation

The WPM was cut into smaller pieces to foster the dissolution in solvent (plate-4a) and the GMRF was extracted and chemically processed by retting, scouring, bleaching, and mercerizing processes

respectively (plate-4b). These were done according to the standard methods adopted by [11, 20, 21]. By melting phenol in an oil bath at 450C and mixing it with liquid 1, 1, 2, 2-tetrachloroethane in the ratio 60/40 w/w, the solvent for dissolving WPM was prepared using the standard procedure described by [11, 20, 22].

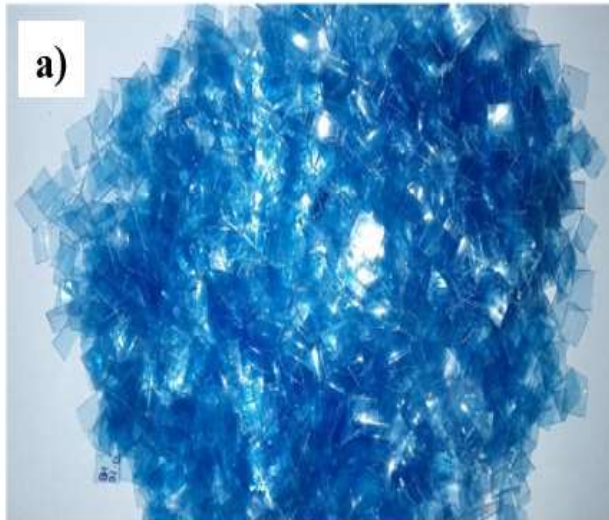


Plate-4a: Pulverized Waste Plastic Material **Plate-4b: Chemically processed Grewia mollis Root Fibre**

Preparation of Waste Plastic Material Solution

The pulverized or crushed WPM (plate-4a) was added in a beaker filled with phenol-1, 1, 2, 2-tetrachloroethane solution and heated to 1000C (plate-5). The mixture was agitated until the entire WPM dissolved, producing a thick liquid according to the standard methods reported by [11, 20, 21].



Plate-5: Waste Plastic Material Solution

Formulation of Grewia mollis Root Fibre Reinforced Waste Plastic Material Composites

The composite was prepared using hand layup technique adopted by [11, 20, 21]. An aluminum mold was prepared and de-bonding agent was first introduced on the inner area of the mold followed by a pigmented gel coat to give high quality surface finish. 20g of the crushed fibre was manually laid in the mold randomly and the melted WPM was poured and casted into the mold. 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 mold, labeled and finally stored at room temperature in an open space in the laboratory for further use (plate-6).



Plate-6: Formulated Grewia mollis Root Fibre Reinforced Waste Plastic Material Composites

Characterization of Grewia mollis Root Fibre Reinforced Waste Plastic Material Composites:

The moisture absorption along with the mechanical performance for the treated and untreated GMRF reinforced WPMCs were investigated according to American Society for Testing and Material (ASTM) standards.

Moisture Absorption Test (MAT)

The test was conducted according to ASTM D355 standard using a moisture analyser device. 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 moisture allowed us to calculate the proportion of moisture absorbed. The effect of moisture absorption behavior for the treated and untreated GMRF under study as a function of time from 24–168hours were studied and recorded using the formula provided by [11, 20, 21] as shown below:

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

Tensile Strength Test (TST)

The test was carried out in accordance with ASTM D638-99 standard using an Enerpac Universal Hydraulic Digital Material Testing Machine (model: H50KS-0404, Hounsfield Series S, UK) with a cross-head speed of 10mm/min and a span distance of 50mm. The composite samples were cut with dimensions of thickness (t) of 3 mm and width (b) of 15mm and mounted on the machine and the tensile force were noted and recorded. The effect of tensile strength (TS) on the treated and untreated GMRF reinforced WPMCs as the concentration of NaOH varies were studied and recorded using the formula described by [11, 20, 21] as shown below:

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

Where: σ_t = Tensile stress of the composite sample (MPa), p = Applied load (N), A = Width * thickness of composite sample (mm).

Compressive Strength Test (CST)

The test was performed according to ASTM D695-97 standard using an Enerpac Universal Hydraulic Digital Material Testing Machine (model: HUNG TA INSTRUMENT CO. LTD., Taiwan). The composite materials were cut into cuboid shapes with dimensions of thickness (t) of 3mm and width (b) of 15mm and placed on the machine and compressed. The compressive load was applied on the composite samples until failure occurs and the load was noted and recorded as well. The effect of compressive strength (CS) on the treated and untreated GMRF reinforced WPMCs as the concentration of NaOH varies were studied and recorded using the formula adopted by [23] as depicted below:

$$\sigma_c = \frac{p}{bxt} \quad (3)$$

Where: σ_c = compressive stress of the composite sample (MPa), p = load (N), b = width of the composite sample (mm), t = thickness of the composite sample (mm).

RESULTS AND DISCUSSION

Effect of Moisture Absorption on *Grewia mollis* Root Fibre Reinforced Waste Plastic Material Composites

The properties of fibre that was subjected to treatment by different concentrations of sodium hydroxide were obtained along with that of the untreated fibre and were presented using descriptive statistics of percentage (%) scatter plot (Fig-1).

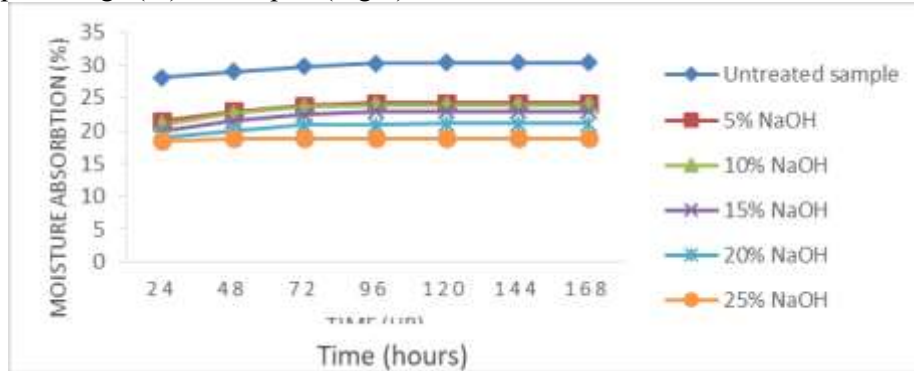


Fig-1: Effect of moisture absorption on *Grewia mollis* Root Fibre Reinforced Waste Plastic Material Composites against time.

The result obtained shown that the absorption rate was very high at first 24 hours and steadily increased up to 96 hours. This gradual increase in moisture absorption could be as a result of low cross-linking density between the fibre and the matrix [24]. 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 Fig-1. These observations agree with the investigations of [23, 25].

The higher absorption rate shown by the untreated composites could be due to the low compatibility of the hydrophobic polymer matrix and the present of strongly polarized hydroxyl groups in natural fibre causing smooth interaction between the fibre and the moisture molecules. Thus, when subjected into moisture, it absorbed some volumes of moisture for first hours than the treated fibres, hence, resulting to a poor moisture resistance [26-29]. The lower absorption rate for the treated 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 physiochemical and mechanical properties of the composites with higher concentration of sodium hydroxide [11, 20, 21, 23, 26, 30].

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 moisture absorption and that the composite treated with 25% has the lowest. This demonstrates that when NaOH concentration rises, moisture absorption falls. This indicates that there is a direct relationship between the moisture absorption rate and the NaOH content. According to reports, mercerization tends to reduce moisture absorption [26].

Effect of Tensile Strength (TS) on *Grewia mollis* Root Fibre Reinforced Waste Plastic Material Composites

The effect of TS on the treated GMRF reinforced WPMCs as the concentration of NaOH varies along with that of the untreated one were presented using bar chart (Fig-2).

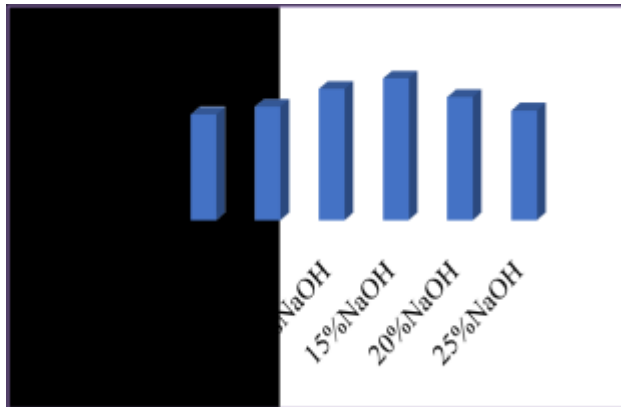


Fig-2: Tensile strength variation of *Grewia mollis* Root Fibre Reinforced Waste Plastic Material Composites as the concentration of NaOH varies.

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 [11, 20, 21]. This implies that composites treated with 10–15% gave better results than those treated with 20–25% as depicted in Fig-2. This is because at low (%), the GMRF is highly compacted by the polymer matrix (WPM) 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 composite [26]. There is slight difference in the trend as 15% emerges as the best with tensile value of 44.05MPa compared to untreated GMRF reinforced WPM matrix with tensile value of 32.85MPa. Therefore, on the basis of % NaOH, threshold point of 15% had the optimum set of mechanical properties. This result agrees with the investigations of [11, 20, 21, 29]. This may be due to the fact that natural fibres are characterized by high moisture 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 mechanical properties of the composites as reported by [11, 26].

Effect of Compressive Strength (CS) on *Grewia mollis* Root Fibre Reinforced Waste Plastic Material Composites

The effect of CS on the treated GMRF reinforced WPMCs as the concentration of NaOH varies along with that of the untreated one were presented using bar chart (Fig-3).

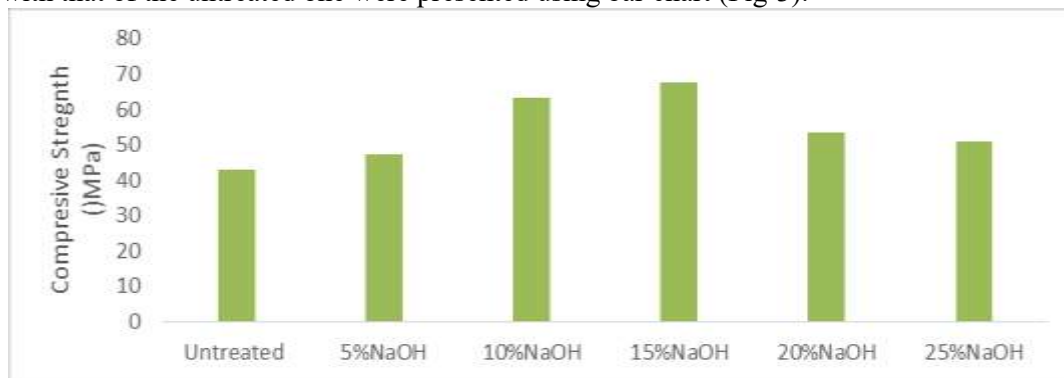


Fig-3: Compressive strength variation of *Grewia mollis* Root Fibre Reinforced Waste Plastic Material Composites as the concentration of NaOH varies.

The result revealed that untreated composite gave poor CS with Compressive value of 43.02MPa compared to composites treated with 5–25%NaOH. This may be due to the fact that natural fibres are

characterized by high moisture 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 mechanical properties of the composites as reported by [11, 26]. This implies that high strength is observed in treated composites which increase 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 [23].

This signifies that composites treated with 10–15% gave better results than those treated with 20–25% as depicted in Fig-3. This shows that bonding between the fibre and the matrix was very low at higher percentage (%) above 15%NaOH resulting to subsequent decrease in the CS of the composite panels treated with 20-25%NaOH as observed in the current study and same was reported in the work of [23]. There is slight difference in the trend as 15% emerges as the best with compressive value of 67.50MPa compared to the rest treated GMRF reinforced WPM matrix with compressive values of (5%=47.20, 10%=63.20, 20%=53.40 and 25%=51.00) MPa respectively and therefore had the optimum set of mechanical properties. This result is in agreement with the report of [23, 31, 32]. This could be due to the facts that alkali treatments remove the lignin and hemicellulose content of the fibre making it well bonded with the polymer matrix and improvement seen in their interfacial bonding which gives necessary strength [23, 33, 34].

CONCLUSION

The composite panels were successfully formulated from waste plastic materials (waste FARO water bottles) and *Grewia mollis* root fibre. The result revealed that chemical treatments significantly reduce the moisture content of the produced composites and improved their mechanical attributes and the optimum improvements were found at 15% for both tensile and compressive strength. This finding clearly showed that the formulated *Grewia mollis* root fibre reinforced waste plastic material composites treated with 15%NaOH exhibited better resistance to moisture and present good mechanical properties. In working towards an environmentally friendly society, waste FARO water bottles can be converted as matrix for *Grewia mollis* root fibre composite formulation which encouraged the conversion or recycling of waste in our environment. It can also increase the quantity of natural fibre reinforced polymer composites in the market and lower its price.

The alkali treated fibre reinforced polymeric composites exhibited better characteristics based on their studied physicochemical and mechanical properties than the untreated fibre reinforced polymeric composites. Hence, could be sensitive to a wide range of applications, especially where high tensile and compressive strength variations are required. This conclusion is supported by previous researches that alkali treated fibre reinforced polymeric composites offered superior mechanical properties than the untreated fibre reinforced polymeric composites. This work may therefore, introduce a novel polymer composite derived from *Grewia mollis* root fibre and waste FARO water bottles into the allied industry.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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