Effects of Alkaline Treatment on the Mechanical Properties of Costus Afer-LDPE Composite

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ABSTRACT

The use of Bush cane (*Costus afer*) stem fibre as a filler in low density polyethylene (LDPE) matrix was studied at filler sizes (FS) of 150, 300, 600 and 2000 μm. The study utilized NaOH-treated and untreated samples obtained by melt-mixing to test for the mechanical properties of the composite. The composites were tested for tensile strength, flexural strength and hardness with respect to variations of component weight ratio and filler sizes. The study was carried out at 20 - 50% filler weight (FW) ratio. Tensile strength for the treated and untreated samples increased to maximum filler size at 18.52 and 15.93 N/m^2 respectively. Percent enhancement of tensile strength in treated samples by filler size was 17.22% on average from 150 to 2000 μm and by filler weight on average was 20.4% from 20 - 50%. Experimental flexural strength increased with increase in filler size from 126.8 to 161.72 MPa for the treated samples and 125.33 to 132.49 MPa for the untreated samples at 150 and 2000 μm respectively. Calculated flexural strength increased from 650 MPa at 20 % FW and 150 FS to a maximum of 1768 MPa at 50% FW and 2000 FS for the treated samples, while that for the untreated samples was 531 MPa at 20% FW and 150 FS to 1323 MPa at 50% FW and 2000 μm FS. Calculated hardness decreased with filler size, while experimental hardness increased with filler size to a maximum. Treated composites showed better mechanical properties than the untreated indicating that the treatment or modification offers improvement of mechanical properties.

Keywords: Composite, Tensile strength, Flexural strength, Hardness, *Costus afer*, low density polyethylene. Filler size, Filler weight

INTRODUCTION

Fibres in general are materials of great use to man's domestic and industrial needs. Natural fibres in particular have been in use from the earliest civilization either as single or composite material. By virtue of their supportive strength, early civilizations had used plant fibres as grass or straw to reinforce clay for bricks in buildings (Holy Bible, Exodus 5:8). In modern times, fibres have found use as fibreglass in plastics, automotive and aerospace components. Fibres from plants such as flax, jute and hemp are greatly used as reinforced composite materials for door panels, furniture, shelves and other automotive interior. There is a growing preference of natural fibres to synthetic forms because of the advantages of environmental friendliness, lower economics, renewability, biodegradability, abundance and comparatively good mechanical properties (Zhou et al., 2016).

Plastic materials have been a source of adverse environmental issues in many places and one way of recycling and mitigation of its effects is to melt-mix with fillers to form composite materials for further application.

The use of cellulosic fibres in some polymeric materials such as thermoplastics and thermoset has been limited by reason of difficulty in filler dispersion in the matrices. Poor interactions and poor interfacial adhesion between some types of fibres and polymeric matrices have been reported (Lee et al., 2021). Composites of the sort have also been reported to have inherent problems as high water absorption and incompatibility with the polymer matrices (Mohammed et al., 2023). Low density polyethylene (LDPE) is a soft and flexible thermoplastic polymer. It is different from the heavier analogue, high density polyethylene (HDPE) due to greater branching of the carbon chains which makes the structure more open and more flexible.

The mechanical characteristics of granular starch and low density polyethylene (LDPE) composites were examined in relation to the presence of compatibilizer, granule size, and starch volume fraction (Willet, 1994). Although the proportionality constants were less negative than the anticipated values, the tensile strength matched the theoretical predictions. Compatibilizer addition resulted in a large rise in the composite tensile modulus but no discernible change in the composite's elongation or tensile strength. The composite moduli data, when analyzed at 15 GPa, were found to be significantly lower than the modulus of cellulose but to be significantly greater than most unfilled synthetic polymers of commercial importance.

Herrera-Franco and Aguilar-Vega (1997) investigated the impact of fibre treatment on the mechanical characteristics of LDPE-henequen cellulosic fibre composites. Comparing the composite materials' tensile strength to that of LDPE, a 50% increase was observed. Young's modulus increased significantly for the composite materials, and it is now comparable to that of LDPE.

Oromiehie, lari, and Rabiee (2013) investigated the mechanical, thermal, and physical characteristics of maize starch/LDPE composites. The composites of low-density polyethylene (LDPE) and low-density polyethylene/thermoplastic starch (LDPE/TPS) at different combinations of TPS were made and tested for tensile strength and elongation at break and Young's modulus among other parameters. It was shown from the results that the composite film's water absorption and density were increased by the additions of starch content in the LDPE/TPS composites. While the tensile strength and elongation at break decreased with growing composite starch levels , the Young's modulus improved.

The dynamic mechanical properties of low-density polyethylene (LDPE) composites reinforced with short sisal fibre were investigated by Joseph, Thomas, and Pavithran (1993). The dynamic mechanical properties of low-density polyethylene filled with isocyanate-treated and untreated short-sisal fibre composites were studied as a function of temperature and frequency. A decrease in the mechanical loss factor was seen when short sisal fibre was added to LDPE, but increases in the storage and loss moduli (E' and E"). When the effects of fibre-matrix adhesion on the composites' viscoelastic properties were examined, it was discovered that the storage modulus increased as adhesion did. Investigations were also conducted into the effects of loading, orientation, and fibre length on the dynamic mechanical characteristics. The temperature always caused the storage moduli (E') and loss moduli (E") to decrease and increase, respectively.

Sever (2010), examined the effect of treated oligomeric siloxane on the mechanical properties of alkali-treated jute fabric-reinforced low-density polyethylene (LDPE) composites. Some mechanical properties of the treated and fabricated composites were evaluated. There was an upward increase in tensile strength from 17.5 MPa for untreated jute fabric/LDPE composite to 27.7 MPa for alkali and oligomeric siloxane-treated jute fabric/LDPE composite. A 39% increase was observed in the flexural strength for the same sample. The effect of siloxane treatment after the alkali-treatment of jute fabric on interlaminar shear strength of jute/LDPE composite brought about 98% improvement. It was shown that both the oligomeric siloxane treatment and the alkali treatment significantly increased the adhesion between jute fibre and LDPE.

According to Sdrobis et al., (2012), low-density polyethylene (LDPE) was reinforced with unbleached and bleached Kraft cellulose pulp fibres treated with a long chain carboxylic acid under cold plasma conditions. The modification was made to improve the dispersability and the interfacial adhesion between the cellulose and matrix. SEM, contact angle measurements, TGA, DSC, processing behavior, and mechanical and rheological characteristics were used to describe the samples. It was discovered that the majority of the properties were enhanced with incorporation of the modified pulp fibres into the composite matrix.

The mechanical behaviour of short treated and untreated bamboo fibre reinforced epoxy based composites was investigated by Lokesh et al.,(2020). They observed that the mechanical properties of the composites such as tensile strength, flexural strength and impact strength were highly influenced by the NaOH treated fibres used.

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The foregone review reveals some works carried out on the mechanical properties of natural fibre reinforced-polymer composites. However, there exist a knowledge gap in the use of the species *Costus afer* for such properties. Herein, we present the effect of alkaline treatment on the mechanical properties of LDPE composite reinforced by *Costus afer* stem powder.

Experimental

Materials: LDPE was obtained from Indoroma, Eleme Petrochemicals, Port Harcourt, Nigeria. Reagent grade Sodium Hydroxide and acetic acid were obtained from Sigma-Aldrich. *Costus Afer* stems were obtained from Efeke-Ama, community in Amassoma, Bayelsa State, Nigeria. Other materials used include improvised mild steel mold, Hounsfield Tensometer W3179 and Universal Testing Machine WP1195.

METHODS

Filler sample preparation: *Costus afer* stems were cut, washed and dried for 24 hours in a vacuum oven at $60-80℃$ to remove moisture. Dried samples were ground using a machinery grinding mill and sieved into mesh sizes of 150, 300, 600 and 2000 μm . The samples were first soaked in 5% NaOH for 60 minutes, after which it was washed with distilled water. The residue from filtration was dried at $60-80℃$ for 24 hours

Composite preparation: Low-density polyethylene (LDPE) and *Costus afer* were thoroughly mixed at filler weight percent of 20, 30, 40, and 50 of the treated and untreated fibre. The LDPE was first melted at $114℃$, homogenized with the fibre filler and transferred to a mild steel mold for shaping and fabrication.

Mechanical testing: After fabrication, test specimens were subjected to various mechanical testing according to ASTM standards. The tensile and flexural strength of fabricated composite were determined using Housfield Tensometer W3179. Gauge length of 50 mm was used in accordance to ASTM D 638.

Experimental Data Analysis: Mechanical testing data was obtained for untreated and untreated composites in replicate readings and were analyzed for tensile strength, flexural strength and hardness. A comparative analysis between the experimental and calculated was done for the flexural strength and hardness. Data analysis and interpretation were carried out with the aid equations to interpret the data and establish the variations in mechanical properties

Tensile strength (TS) was calculated using equation 1

$$Tensile\ strength = \frac{Breaking\ force\ (N)}{Original\ cross\ sectional\ Area(m^2)} \tag{1}$$

Flexural strength (σ) was calculated from the equation (2)

$$\sigma = \frac{3FL}{2bd^2} \tag{2}$$

Where,

F is the load (force) at fracture point (N)

L is the distance between support points

d is the thickness of specimen

b is the width of specimen

Hardness of the composite was calculated from the Vicker’s hardness value as given in equation (3)

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$$HV = \frac{2F \sin\left(\frac{\alpha}{2}\right)}{D^2} = 1.854 \frac{F}{D^2} \quad (3)$$

Where,

HV= Hardness value

F = Test force (N)

α = Indenter face contact angle = 136°

D = Average diagonal length (m)

HV can be converted to MPa GPa by multiplying the result by 9.807 and 0.009807 respectively.

RESULTS AND DISCUSSION

The variation of the filler-matrix mixing of the tensile strength, flexural strength and hardness of the treated and untreated LDPE-*Costus Afer* composite are given in the figures 1 to 5. Generally, the mechanical properties of the composites increased with increase in filler sizes

Variations of the tensile strength measurements for the untreated and treated composites are shown in figures 1 to 1b: the results show that *Costus afer* filler increased the tensile properties of LDPE matrix; also the treatment with sodium hydroxide significantly enhanced the tensile strength of the composites. The enhancement due to the treatment increased with increase in the filler size; this is also observed with the percent filler weight ratio. Tensile strength for treated and untreated samples increased to maximum filler size at 18.52 and 15.93 N/m^2 respectively within the range of filler size composition. Average tensile strength enhancement was 17.22% throughout the filler size range and a maximum of 19.4% for 600 µm. Tensile strength enhancement by filler weight was 20.4% by average and a maximum of 21.64% at 50% filler weight. Average tensile strength enhancement at 600 µm was 20.98% by average of filler weight and a maximum of 20.98% at 50% filler weight.

The calculated flexural strength (σ) also showed enhancement by the treatment as can be seen in figure 2 to 2b. Enhancement of calculated flexural strength by filler size was 7.53% on average over the range of sizes and a maximum of 22.06% of 2000 µm. Calculated flexural strength increased from 650 MPa at 20 % FW and 150 FS to a maximum of 1768 MPa at 50% FW and 2000 FS for treated samples, that for   untreated samples was 531 MPa at 20% FW and 150 FS to 1323MPa at 50% FW and 2000 FS. Enhancement of calculated flexural strength by filler weight was 33.59% on average and a maximum of 33.75% at 20% filler weight of 2000 µm. The treated experimental flexural strength results also present higher values than the untreated composite. A linear increase of experimental flexural strength with filler weight was observed for both the treated and untreated composites. Experimental flexural strength increased with increase in filler size from 126.8 to 161.72 MPa for treated samples and 125.33 to 132.49 MPa for untreated samples at 150 and 2000 µm respectively. Enhancement of experimental flexural strength by filler size was 10.51% on average of the range of values and a maximum of 22.06% of 2000 µm, while that filler weight was 33.57% on average and a maximum of 33.72% at 20% filler weight of 2000 µm. For the experimental hardness, the treated composite also presented a higher hardness in excess of 51.89%, 56.28%, 50.28% and 47.95% respectively as the filler size decreases. Calculated hardness also increases with filler size up to a maximum and then decreases but it is also much higher for the treated composite. The enhancement factor for this property also has a sharp difference between the treated and the untreated. Treatment enhancement by NaOH followed the observations of previous studies with other fillers as shown in the literature. Alkaline treatment enhancement may be due to H-bonding OH groups which provide strong intermolecular interactions that imparts greater strength than the untreated samples (Boey et al., 2022).

Overall, the study showed that all mechanical properties tested for, were all greatly enhanced by *costus afer*

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filler, as well as the alkaline treatment of the composite.

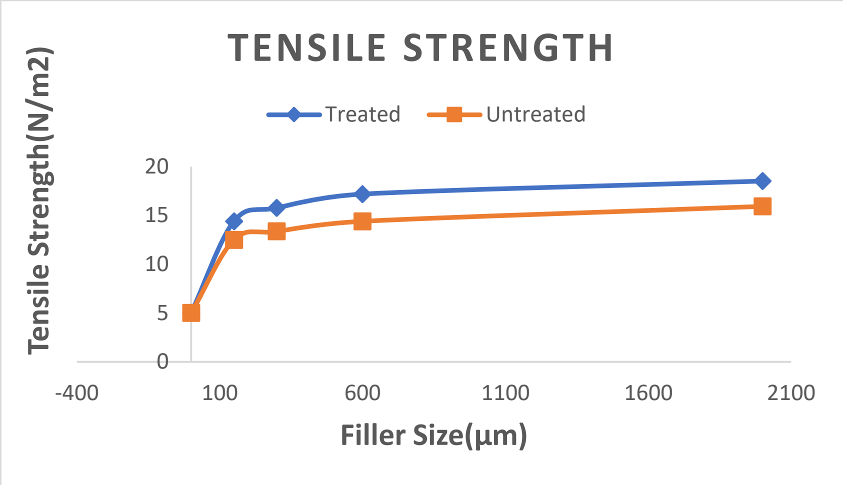

Figure 1. Linear plot of variation of tensile strength with filler size for treated and untreated LDPE-*Costus afer* composite

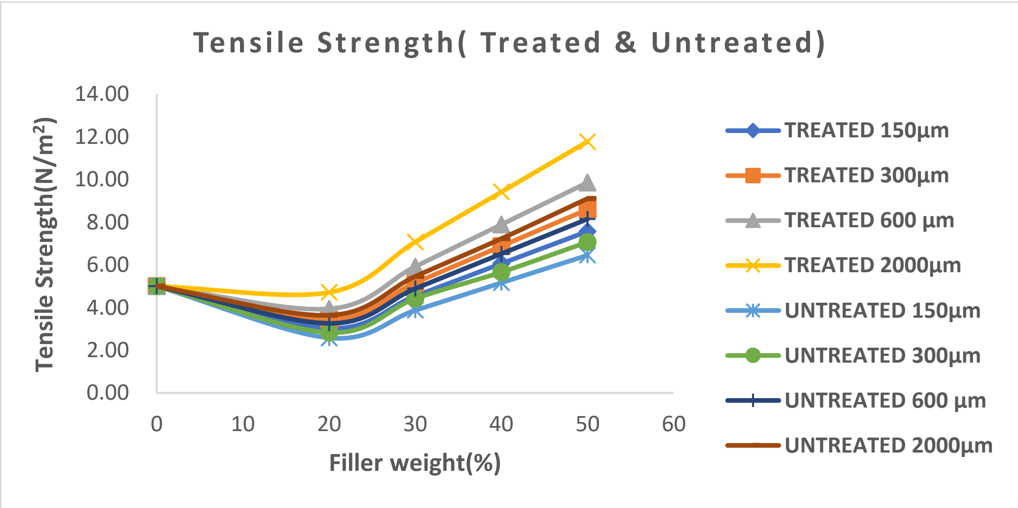

Figure 1a. Linear plot of variation of tensile strength with filler weight by filler size for treated and untreated LDPE-*Costus afer* composite

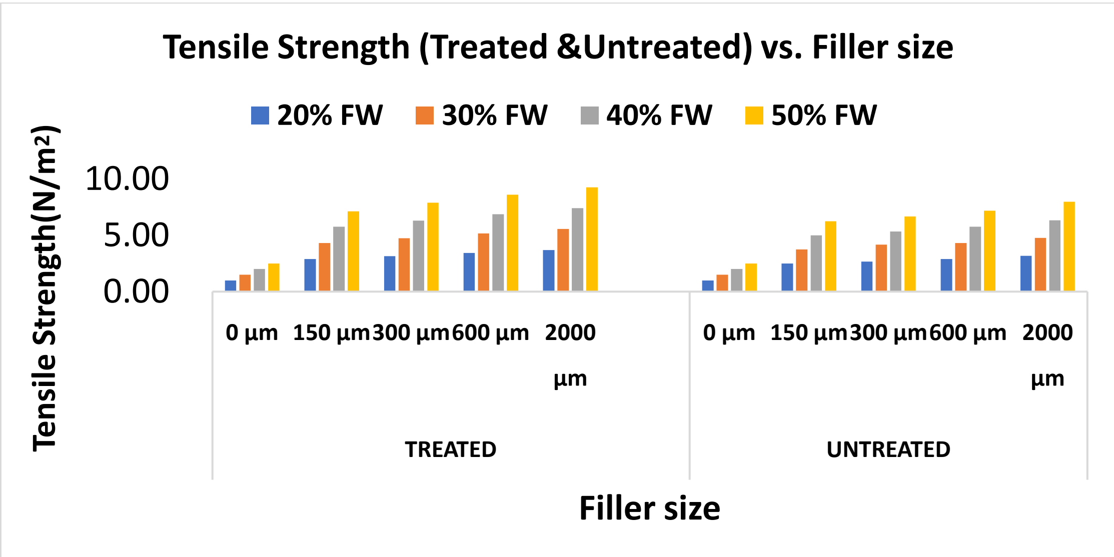

Figure 1b: Comparative Bar chart of the variation of Tensile Strength with filler weight for treated and untreated LDPE-*Costus afer* composite

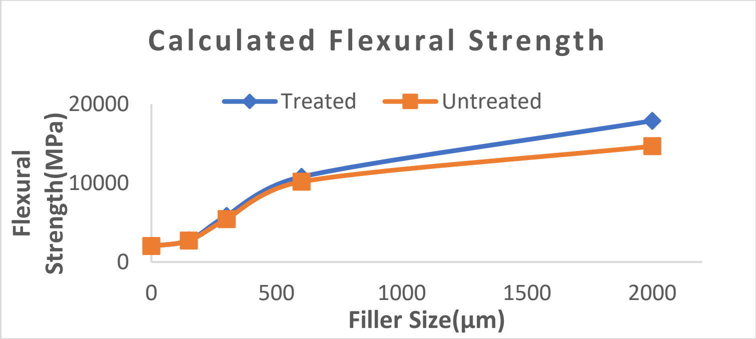

Figure 2. Linear plot of variation of calculated flexural strength with filler size for treated and untreated LDPE-*Costus afer* composite

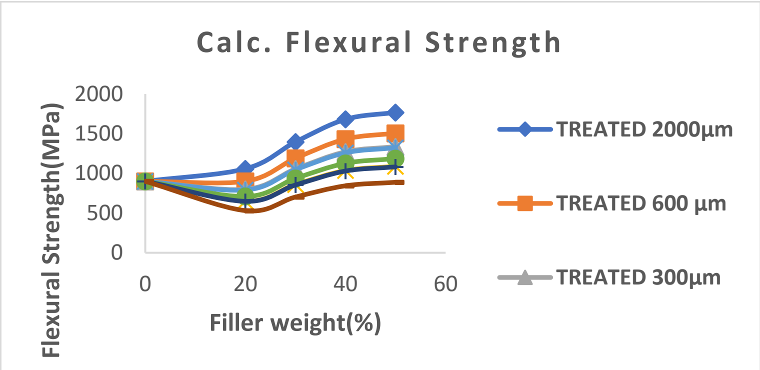

Figure 2a. Linear plot of variation of calculated flexural strength with filler weight by filler size for treated LDPE-*Costus afer* composite

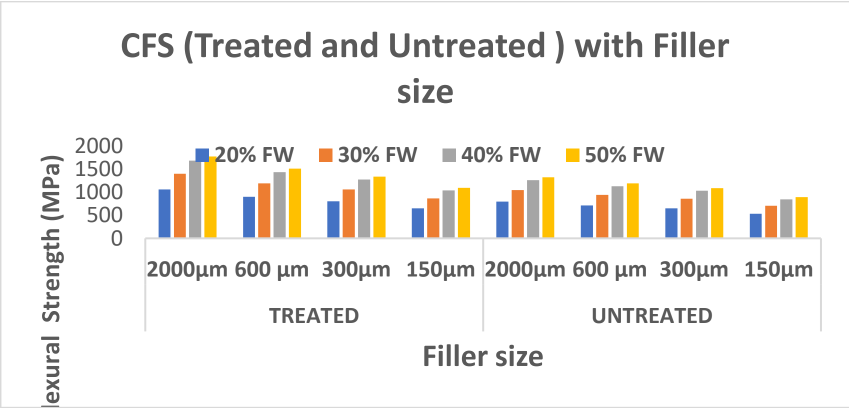

Figure 2b: Comparative Bar chart of the variation of calculated flexural strength with filler size by filler weights for treated and untreated LDPE-*Costus afer* composite

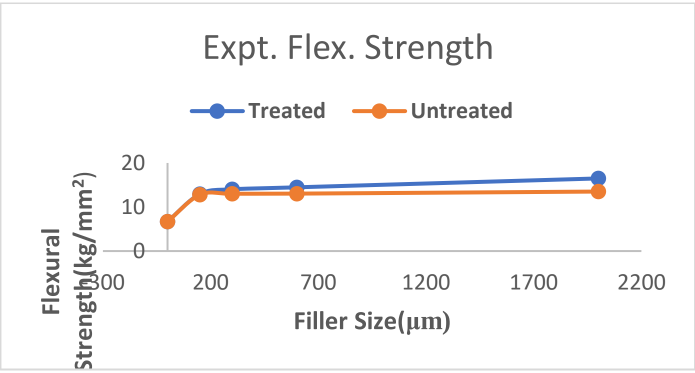

Figure 3. Linear plot of variation of experimental flexural strength with filler size for treated and untreated LDPE-*Costus afer* composite

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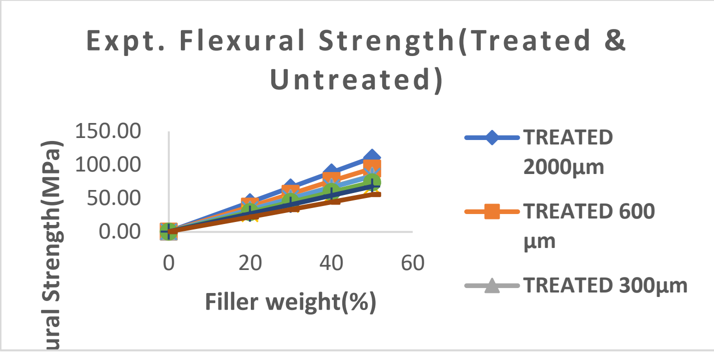

Figure 3a. Linear plot of variation of experimental flexural strength with filler weight by filler size for treated and untreated LDPE-*Costus afer* composite

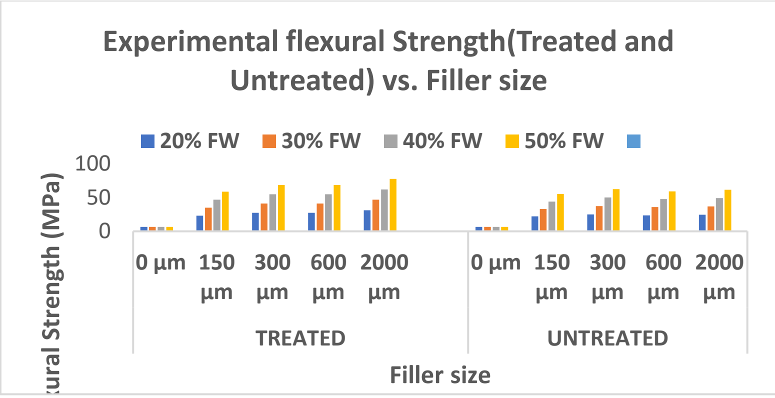

Figure 3b. Comparative Bar chart of variation of experimental flexural strength with filler size for treated and untreated LDPE-*Costus afer* composite

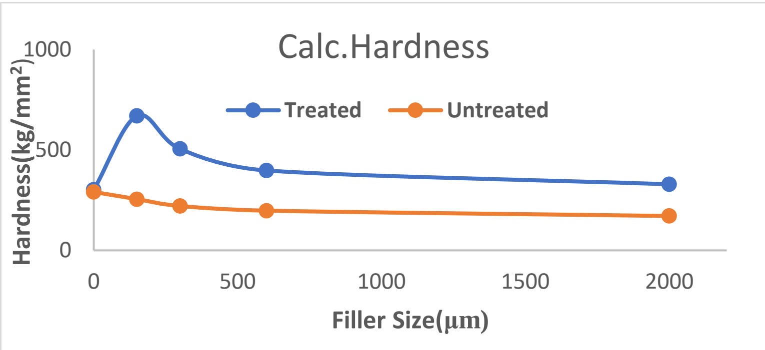

Figure 4. Plot of variation of calculated hardness with filler size for treated and untreated LDPE-*Costus afer* composite

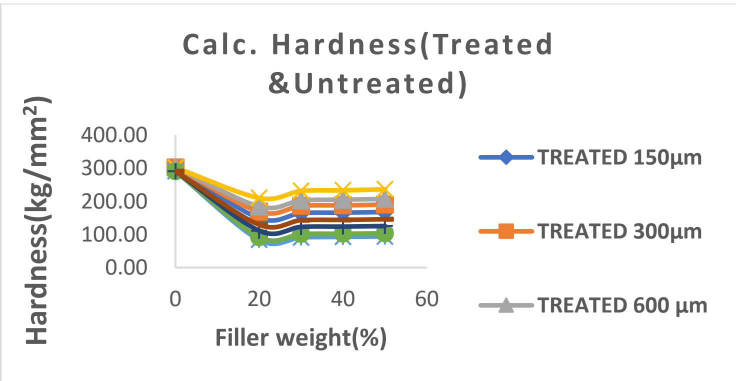

Figure 4a. Linear plot of variation of calculated hardness with filler weight by filler size for treated and untreated LDPE-*Costus afer* composite

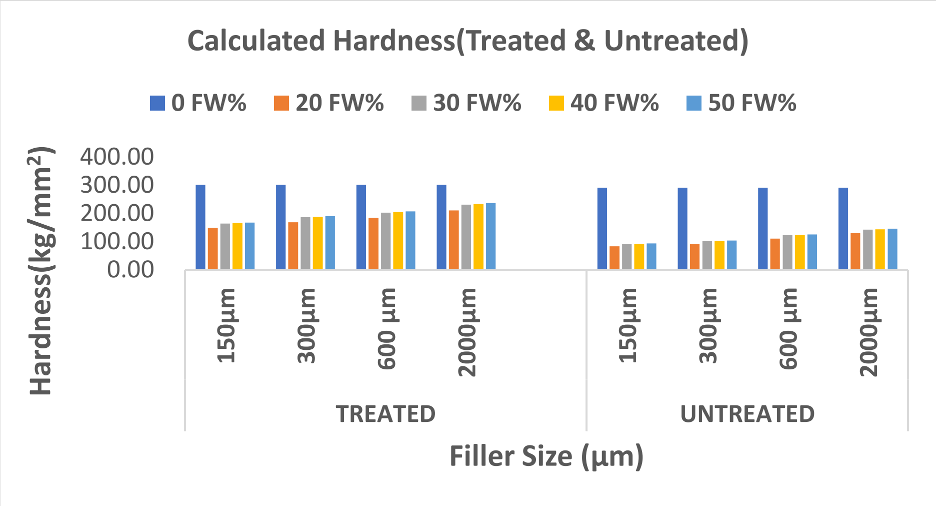

Figure 4b. Comparative Bar chart of variation of calculated hardness with filler size for treated and untreated LDPE-*Costus afer* composite

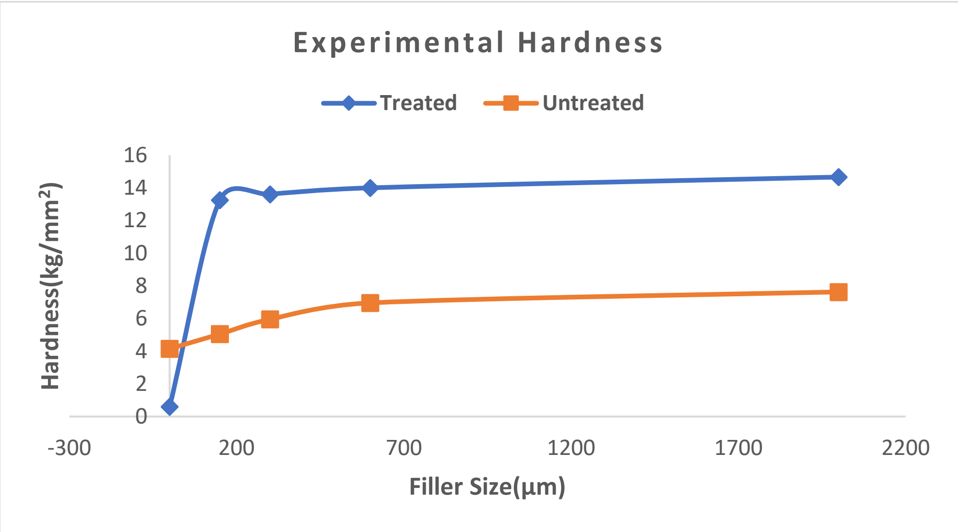

Figure 5. Plot of variation of experimental hardness with filler size for treated and untreated samples

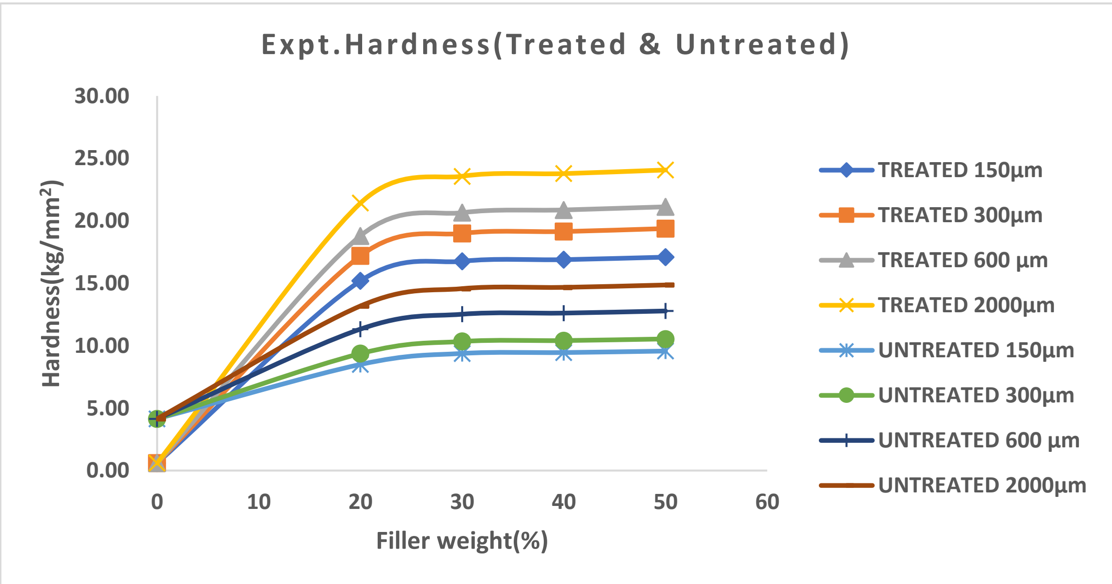

Figure 5a. Linear plot of variation of experimental hardness with filler weight by filler size for treated and untreated LDPE-*Costus afer* composite

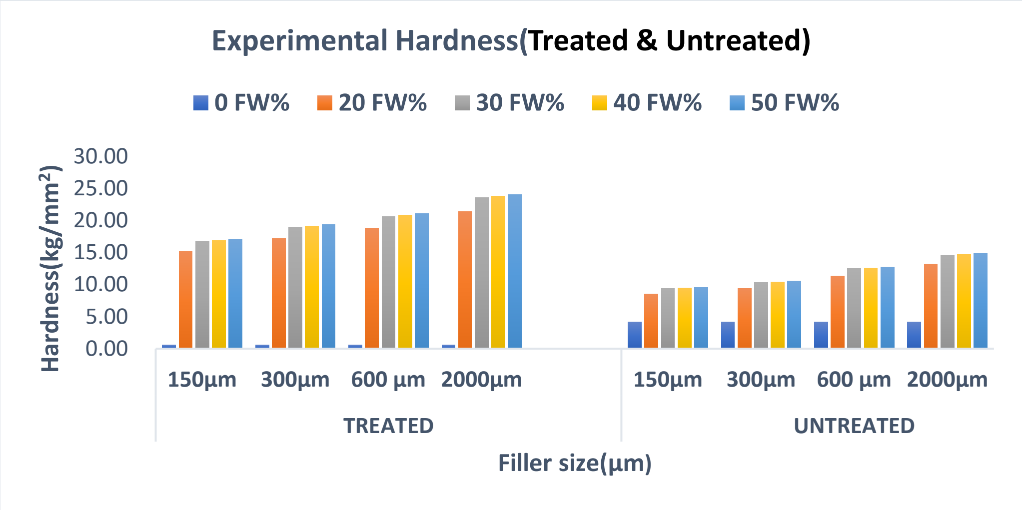

Figure 5b. Comparative Bar chart of variation of experimental hardness with filler size for treated and untreated LDPE-*Costus afer* composite

CONCLUSION

Mechanical properties as tensile strength, flexural strength and hardness of alkali-treated and untreated *costus afe*r-LDPE composite were studied and evaluated. The results showed that alkaline treatment significantly enhanced the aforementioned mechanical properties of the costus *afe*r- LDPE composite. Tensile strength for treated and untreated samples significantly increased with increase in filler size up to a maximum of 600 µm.The flexural strength for treated and untreated samples increased with increase in filler size and filler weight ratio. Calculated hardness decreased with filler size, while experimental hardness increased with filler size to a maximum. Treated composites showed better mechanical properties than the untreated. *Costus afer* stem fibres can serve as a good filler material for the enhancement of mechanical properties of LDPE.

Authors' Declaration

There is no conflict of interest between the authors of this work.

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