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Mechanical properties and water absorption behaviour of treated pineapple leaf fibre reinforced polyester matrix composites

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Abstract

Investigations were carried out to study the effect of treated pineapple leaf fibre (PALF) on the mechanical properties and water absorption behaviour of reinforced polyester composites. PALF was extracted from pineapple plant using wet retting method. Chemical treatment was carried out on it to hinder water content and enhances good adhesion between fibre and matrix. Both the matrix and the fibre were compounded using hand lay-up method at room temperature. The samples were prepared for tensile test, flexural test, hardness test and water absorption test. It was observed that as the fibre content increases within the matrix, there is corresponding increase in the ultimate tensile strength and modulus of elasticity while there was decrease in the elongation at break. Flexural strength, flexural modulus and hardness properties of the developed composites increase linearly from 10 wt% to 30 wt% fibre loading and begin to decrease from 40 wt% fibre loading. The results of the water absorption test showed that the amount of water absorbed by the composite increased with increase in fibre loading.

Keywords

Adhesion, Composites; Mechanical behaviour; Fibre; Miscibility; Hand lay-up method

Introduction

Natural fibres are produced from renewable resources, they are biodegradable and relatively inexpensive compared to the traditionally used synthetic fibres [1]. Fibres of this type are beginning to find their way into commercial applications such as in automotive industries and household applications, for example, hemp and flax, are successfully used as packaging material, interior panels in vehicles, and building components, among others. In addition, natural fibres like banana, sisal, hemp and flax, jute, coconut, local fibres and oil palm have attracted technologist and scientist in consumer goods, low costs housing and other civil structures [2]. There are many plant fibres available which has potential to be applied in industries as raw materials such as pineapple leaf fibre, kenaf, coir, abaca, sisal, cotton, jute, bamboo, banana, Palmyra, talipot, hemp, and flex [3].

Pineapple leaf fibre (PALF) is one of the waste materials in agriculture sector. After banana and citrus, pineapple (Ananas comosus) is one of the most essential tropical fruits in the world [4]. Commercially pineapple fruits are very important and leaves are considered as waste materials of fruit that is being used for producing natural fibres. The chemical composition of PALF constitutes holocellulose (70–82%), lignin (5–12%), and ash (1.1%). Pineapple (PALF) has tremendous mechanical properties and can be applied in making of reinforced polymer composites [5], low density polyethylene (LDPE) composites, and biodegradable plastic composites. Physical and mechanical properties of composites like viscoelastic behaviour processing, tensile strength, flexural strength, and impact are dependent on length of fibre, matrix ratio, and fibre arrangement [6].

The main drawback PALF is hydrophilic nature; it does not make good bonding with hydrophobic matrix, particularly at high temperatures [7]. Interfacial quality between PALF and polymer could be enhanced by using chemical treatments like dewaxing, treatment with NaOH, cyanoethylation, and grafting of acrylonitrile monomer onto dewaxed PALF [8]. Moreover, the surface modification by chemicals like sodium hydroxide (NaOH), 2,4-dinitrochlorobenzene, benzoyl peroxide (BPO), and BPO/acetylation can minimize water absorption and improves the mechanical properties [9]. The moisture absorption of chemically modified PALF-reinforced LDPE composites shows considerably less moisture content [10]. Bonding agent resorcinol (reso), hexamethylenetetramine (Hexa), and silica have good affinity for PALF-natural rubber (NR) and exhibits better adhesion [11].

An automotive component using natural fibres was designed and have proved to be effective reinforcement as simple fillers in thermoplastic and thermoset matrix composites for automotive sectors [12]. A number of investigations have been conducted thereafter on several types of natural fibres such as kenaf, hemp, flax, bamboo, and jute to study the effect of these fibres on the mechanical properties of composite materials [13].

Extensive research has been carried out on the mechanical behaviour of polypropylene composite reinforces with pineapple leaf fibre [14]. The research shows that the fibre lacks compatibility with hydrophobic matrix, the fibre surface was therefore treated with alkaline solution to increase it adherent property with the matrix. Their result shows an increase in the strength of the composites.

Chicken fibre and cow hair was also used to reinforce high density polyethylene and it was found that the impact properties of the chicken feather fibre reinforced composites are significantly better in terms of strength than the control [15]. His result shows that as the fibre content in the composites increases, the flexural strength of the composite reduces.

Chicken feather and quail was also used to reinforce polyester and vinyl ester and it was found that the impact properties of the chicken feather fibre composite increases as the feather content of the polymer increases [16].

Polyester is a synthetic fibre derived from coal, air, water, and petroleum. It is used in the manufacture of many products, clothing, home furnishings, industrial fabrics, computer and recording tapes, automobile bumpers and electrical insulation. Polyester has several advantages over traditional fabrics such as cotton. It does not absorb moisture, but does absorb oil; this quality makes polyester the perfect fabric for the application of water-, soil-, and fire-resistant finishes [17].

However, Polyester have some limitations which includes; high thermal expansion, poor weathering resistance, subject to stress cracking, difficult to bond and poor temperature capability, low tensile strength, brittle. These limitations can be improved on by adding natural fibre to its product during production. This will enhance its properties such as impact strength, flexural strength, tensile strength and hardness and water adsorption property [18].

The use of natural fibres such as sisal, coir, jute, ramie, pineapple leaf and banana leaf fibre have been emphasised to be used as replacement for glass or other traditional reinforcement material in composite. The use of natural fibre is attractive because of its environmental friendly characteristics such as abundance, low cost, low density, biodegrability, flexibility during process, minimal health hazard, readily available and flexural high modulus [19].

The aim of the research was to study the mechanical and water absorption behaviour of Pineapple leaf reinforced Polyester Matrix composite.

Material and method

The materials used for this work are: unsaturated polyester resin, ethyl ketone peroxide and cobalt napthalate supplied by Pascal integrated limited at Akure, Ondo, State, Nigeria, and urea and sodium hydroxide also supplied by Pascal Integrated Limited and pineapple leaf fibre extracted form pineapple leaf.

Extraction of pineapple leaf fibre

The fibre was extracted from pineapple leaf using wet retting method. The pineapple leaf was scratched in other to remove the waxy layer from its surface. The scratched pineapple leaf was immersed in urea solution for seven days. The urea solution was prepared by dissolving 20 g of urea into 1000 ml of distilled water. The pineapple leaf was removed after the seventh day of immersion. The fibre was removed from the pineapple leaf with finger, washed and dried in the sun for 24 hours.

Chemical treatment of pineapple leaf fibre

Prior to composite preparation, the fibre was treated with sodium hydroxide solution in other to improve the surface property of the pineapple leaf fibre. Sodium hydroxide (2M) was dissolved in distilled water and pineapple leaf was immersed for 2 hours at 70°C in water shaker bath. The fibre is further dried in an air blast oven at a temperature of 60°C and stored in a dry environment for composite preparation.

Production of polyester/pineapple leaf fibre composites

The composite was prepared by hand lay-up method. 1g of accelerator and hardener was added to 200 g of polyester resin (mixed ratio 200:1:1). They are mixed thoroughly to form gel. For tensile specimen, half portion of the tensile mould was filled with the polyester gel and pre-determined proportion of chopped pineapple leaf fibres were arranged continuously on the gel, then, the remaining gel was poured to fill up the mould; for flexural specimen, predetermined proportion of the chopped fibres were mixed thoroughly with the gel and poured into the mould. The casts were allowed to cure for 20 mins at room temperature before being stripped from the mould and further curing for 14 days before testing. Several samples with varying fibre content (0, 10 wt%, 20 wt%, 30 wt%, and 40 wt%) were prepared as shown in Table 1.

Table 1. Composite samples formulation table

Sample Designation	Fibre length (mm)	Weight of Polyester Resin (g)	Weight of Fibre (wt.%)	Weight of Catalyst (g)	Weight of Accelerator (g)
A (0 wt.% PALF)	-	200	-	-	-
B (10 wt.% PALF)	186	200	10	1	1
C (20 wt.% PALF)	186	200	20	1	1
D (30 wt.% PALF)	186	200	30	1	1
E (40 wt.% PALF)	186	200	40	1	1

Mechanical test

The composites cast samples were prepared for tensile test, flexural test and micro hardness test

Tensile test

Tensile tests were performed on Instron 1195 at a cross head speed of 10mm/min. the samples were prepared for this test according to ASTM D638 and tensile strength of neat polyester and PALF/Polyester composite samples were determined. At the beginning of the tensile test, the specimen elongates and the resistance of the specimen increases which was detected by a load cell. This value was recorded until a rupture of the specimen occurred. The tensile strength, percentage elongation and young modulus of elasticity were calculated using equations 1-3 respectively.

$$Tensile\ strenght = \frac{load\ at\ break}{(original wigth)(original thickness)} \quad (1)$$

$$\%\ \text{elongation} = \frac{\text{elongation at rupture}}{\text{initial gauge length}} \times 100 \quad (2)$$

$$Young\ modulus = \frac{\dfrac{load\ at\ break}{(original\,width)(original\,thickness)}}{\dfrac{elongation\,at\ point\,on\,tangent}{initial\,gauge\,length}} \quad (3)$$

Flexural test

Flexural strength is the combination of tensile strength and compressive strength. The tests were done on a universal testing machine. The specimens were prepared according to ASTM D790 with dimension 127mm × 13mm × 4mm. the specimens were tested flatwise on a support span resulting span to depth ratio of 16. This means the span is 16 times greater than the thickness of the specimen. The specimen was then placed on two support spans fixed at 100mm.

Hardness test

The hardness of the neat polyester and PALF/polyester composites were measured with the aid Brinell hardness tester (INDENTEC, 2007 model) with ASTM D2240. The samples were indented following the various fibre compositions in the composites. The reading on the machine was noted and recorded.

Water absorption test

Water absorption tests were carried out following the recommendations specified in ASTM D5229M-12. Samples of each composite grade were oven dried before weighing in accordance with ASTM D5229M-12. The weight recorded was reported as the initial weight of the composites. The samples were then placed in rain water maintained at room temperature (25 °C) and at a time interval of 24 hours, the samples were removed from water, dried and weighed. The weight measurement was taken periodically for 336 days which was after water saturation in all the composites had been noticed. The amount of water absorbed by the composites (in percentage) was calculated using equation 4.

$$\%W = \frac{W_t - W_o}{W_o} \times 100 \quad (4)$$

where W is percent water absorption, W_o and W_t are the oven dried weight, and the weight of the specimen after time t, respectively.

Graphical plots of weight gained-immersion time and percent water absorption-immersion time for all the composites were produced and utilized to study the water absorption behaviour.

Results and discussion

The results of the stress-strain curve, variation of ultimate tensile strength, variation of modulus of elasticity, variation of percentage elongation at break, variation of flexural strength, variation of flexural modulus, variation of hardness, water absorption curve, and variation of water absorption behaviour of neat polyester and PALF/polyester composites were plotted using excel and kaleida software and are shown in Figures 1-9 respectively.

Tensile properties of neat polyester and the developed composite

Figure 1 revealed the stress- strain curve of PALF/Polyester Composites tested at a cross head speed of 50mm/min. It was observed from the curve that the tensile strength of the composites increases with increase in the PALF weight fraction.

Figure 2 shows the variation of the ultimate tensile strength for neat Polyester and PALF/Polyester composites. The ultimate tensile strength of the neat polyester is 5.11 MPa. It was observed from the results that the strength of composites increases linearly from 10 wt.% PALF/Polyester composite to 40 wt. % PALF/Polyester composite where the optimum value of 29.19 MPa was observed. The incorporation of treated PALFs into polyester matix at weight fraction of 40 wt.% produced the increase in ultimate tensile strength by about 471%. The general improvement in the ultimate tensile strength of the treated PALF/ Polyester composites is attributed to the enhancement of fibre-matrix interaction and more effective transfer of stress [20].

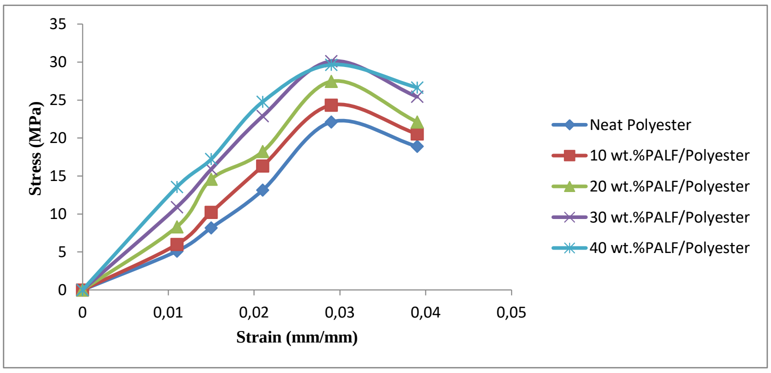

Figure 1. *Stress- strain curve of neat polyester and PALF/Polyester composites*

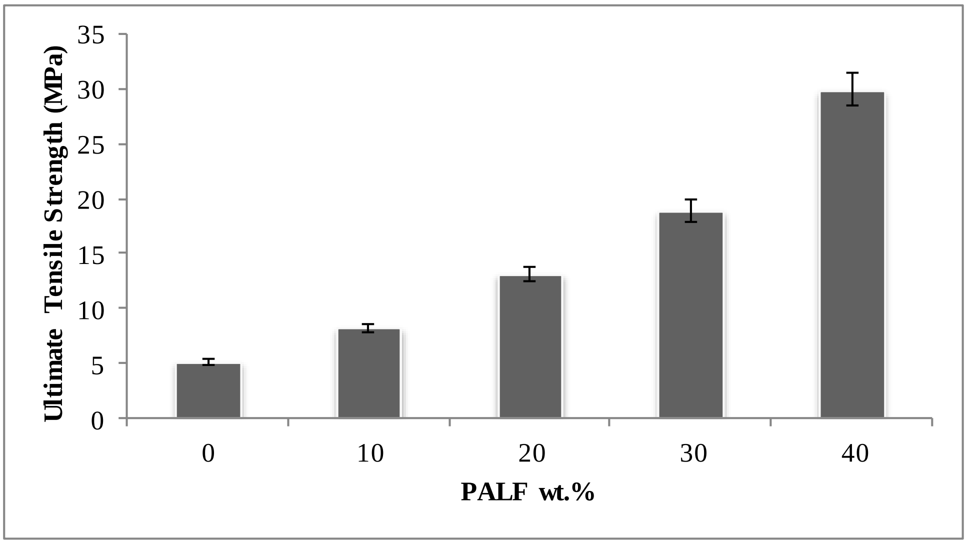

Figure 2. *Variation of ultimate tensile strength of neat polyester and PALF/Polyester composites*

Young's Modulus of Elasticity for Neat Polyester and PALF/Polyester Composites and illustrated in figure 3. The neat polyester have Young's Modulus of Elasticity of 464.55MPa; on increasing the PALFs the modulus values also increases linearly from 10 wt% PAFL weight fraction to 40 wt.% PALF weight fraction. Addition of 40 wt.% PALF enhanced the modulus of elasticity of the composite to 766.92 MPa which is about 65 % increase when compared with the neat polyester matrix. The increase in the Young's Modulus can be attributed to the fibre surface treatment, which allowed strongest adhesion at the fibre-matrix interface; the alkanization of PALF increases the fibre strength by the enhancement of the orientation in the cellulose chain [21].

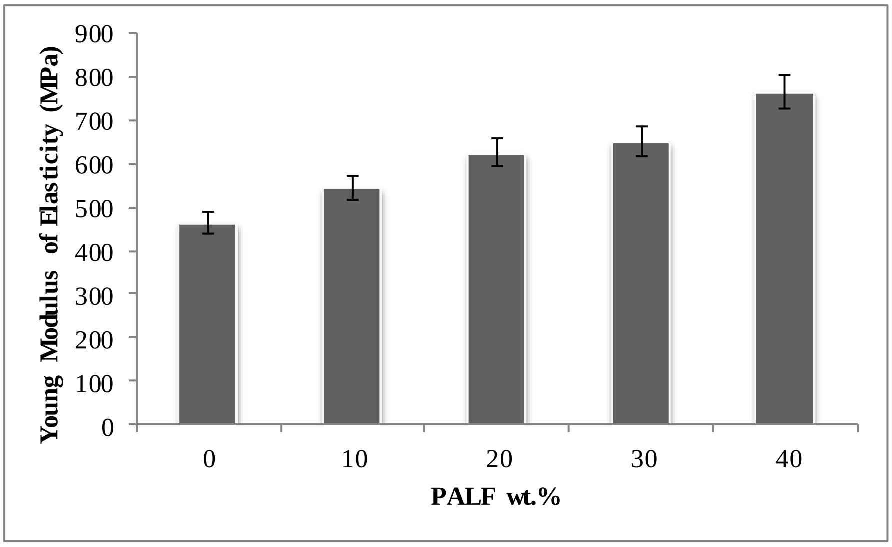

Figure 3. *Variation of modulus of elasticity of neat polyester and PALF/Polyester composites*

Percentage elongation at break values denotes the maximum extension of the samples while in tension. The elongation at break values depends on the fibre/matrix interaction. Figure 4 revealed the variation of the percentage elongation of neat Polyester and PALF/ Polyester composites is 65.37%. From engineering point of view, percentage elongation at break is an important parameter describing the rupture behaviour of the composite materials. The addition of PALF to polyester matrix reduces its percentage elongation from 65.37% at 0 wt.% PALF weight fraction to 9.09 % at 40 wt.% PALF weight fraction. This can be attributed to the stiff fibre that was introduced to the polyester matrix which interrupted the polyester segment mobility and thus turning the thermoset to be more brittle.

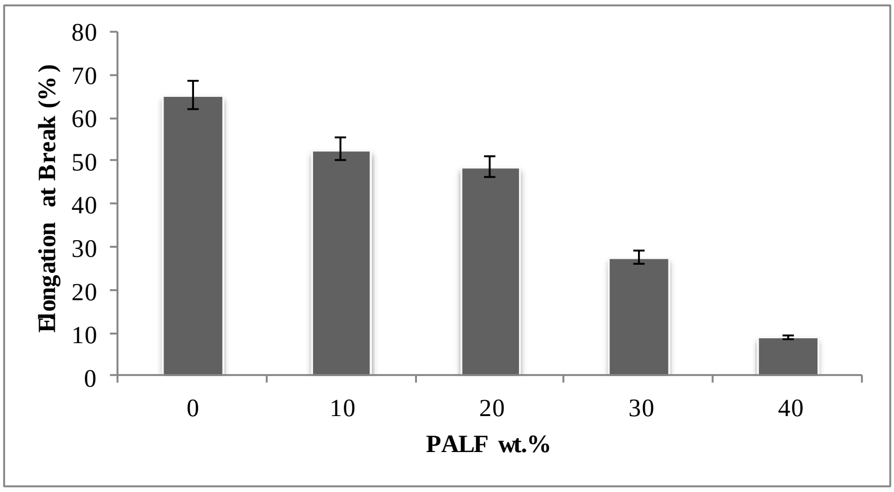

Figure 4. *Variation of percentage elongation at break of neat polyester and PALF/Polyester composites*

Flexural properties of neat polyester and the developed composites

Flexural strength is the ability of the material to withstand the bending forces applied perpendicular to its longitudinal axis. Figure 5 presents the variations of flexural strength of neat polyester and PALF/Polyester composites. The flexural strength of the neat polyester is 25.11 MPa; it was observed from the plot that the flexural strengths of PALF/Polyester composites increase with increase in PALFs loading upto 20 wt.% fibre loading and begin to decrease gradually from 30 wt.% - 40 wt.% PALF loading. At 20 wt.% fibre loading, the flexural strength of the composite is 31.19 MPa which about 24% increase when compared with the flexural strength of neat polyester matrix. Generally, in the case of composites, the resistance to interlaminar failure controls the flexural properties. Therefore, high flexural strengths of composite are due to better interfacial adhesion of at the fibre-matrix interface, which is a result of the chemical treatment of the PALF that enhanced the fibre-matrix interaction and thereby increased the interfacial bond strength and allowed strongest adhesion at the interface [21]. The decrease in the flexural strength at higher fibre loading (20 wt.% in this case) is as a result of non-uniform stress transfer due to PALFs touching each other within the matrix. Similar report was made for jute reinforced polyester amide fibres [22].

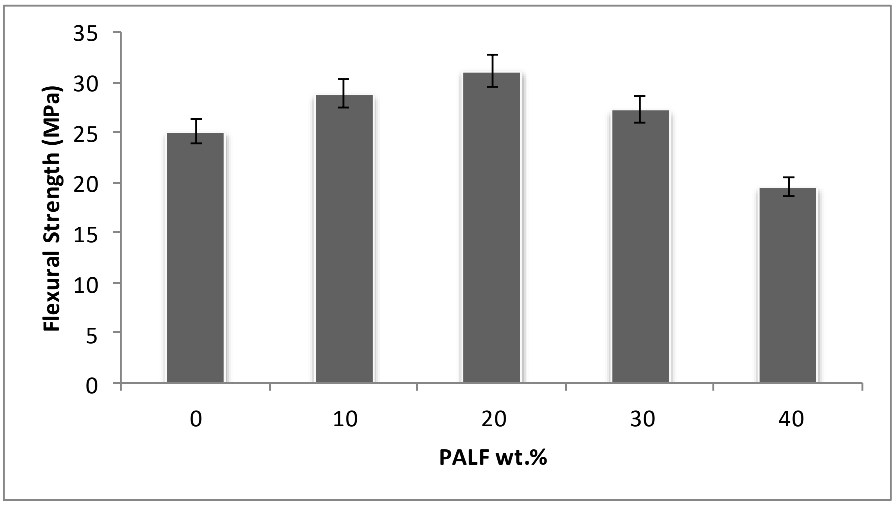

Figure 5. *Variation of the flexural strength of neat polyester and PALF/Polyester composites*

Figure 6 shows the variation of the flexural modulus of neat Polyester and PALF/Polyester composites. Flexural modulus is used as an indication of a material's stiffness when flexed. It is well known that the improvement in the modulus depends on the morphology of composites [23]. From the plot, the flexural modulus of the neat polyester matrix is 500.55 MPa. The flexural modulus of the composites follows the same trend with the flexural strength, there was gradual increase in the modulus from 10 wt.% - 20 wt.% fibre loading and begin to decrease as from 30 wt.% - 40 wt.%. The optimum value for PALF/Polyester composite is 704.59 MPa which is about 40.76% obtained at 20 wt.% fibre loading. The reduction in the flexural modulus at higher fibre loading is a result the fibres touching each other which resulted into stress concentration at the tips of PALFs within the matrix.

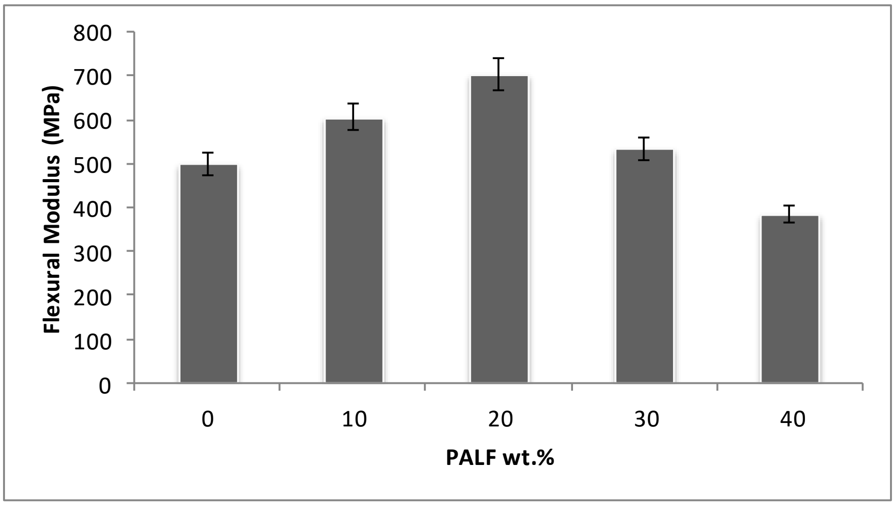

Figure 6. *Variation of flexural modulus of neat polyester and PALF/Polyester composites*

Hardness properties of neat polyester and the developed composites

Hardness is the resistance of a material to surface indentation. Figure 7 revealed the hardness of the neat polyester and PALF/Polyester composites. It was observed that the addition of fibre to polyester increases the hardness property up to 30 wt% after which there is reduction in the hardness at higher fibre loading (40 wt%). At the point where there is high proportion of fibre reinforcement loading with respect to the matrix, the fibres begin to touch each other which resulted into stress concentration at the tips of the fibres thereby reducing the hardness of the developed composites. This result correlates with [15]; in their research, they studied the mechanical properties of chicken feather and cow hair fibre reinforced high density polyethylene composites and observed that there was reduction in the mechanical properties of the composites developed at higher weight fraction of the chicken feather and cow hair fibre.

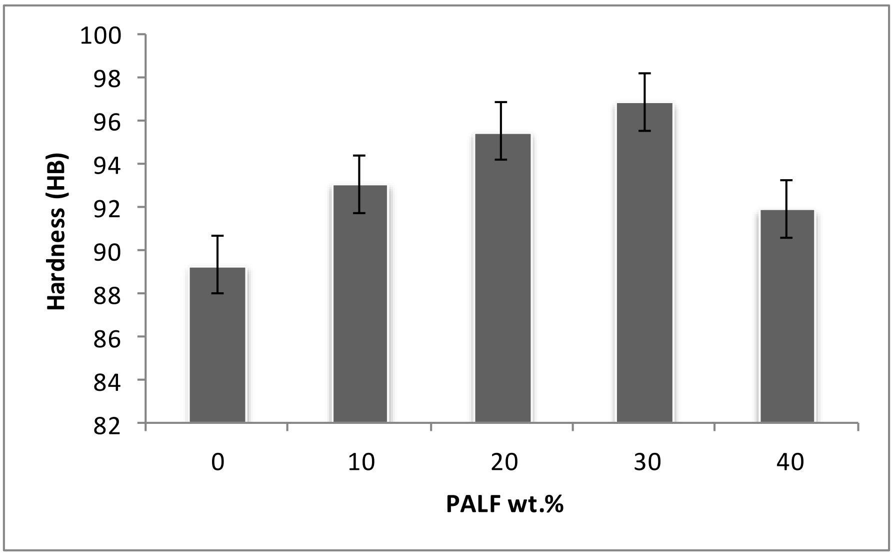

Figure 7. *Variations of the hardness of neat polyester and PALF/Polyester composites*

Water absorption behaviour of neat polyester and the developed composites

Composites were immersed in distilled water at room temperature for about 336 hours. The weight gains curves and the bar-chart as a function of time and water absorption curve are shown in Figures 8-9. Each point on the curve is an average of three samples of each specimen composition of the composite. It was observed from the graph that the water absorption by the composite increases with immersion time although the rate of absorption decrease with increased time. It was also observed that the composite attains equilibrium after 336 hours. The amount of water absorbed increases with fibre content. The water absorption property of PMCs reinforced with natural fibres and their derivatives is dependent on the amount of the fibre, fibre orientation, immersion temperature, area of the exposed surface to water; also the permeability of fibres, void content, and hydrophilicity of the individual components (in this case the PALF and the polyester matrix) [24]. In the case of the composites produced, exposure to water makes the hydrophilic PALF to swell. As a result of fibre swelling, micro cracking of the polyester occurs particularly along the fibre/matrix interface which gives room for further water penetration. The the swelling stresses that develop under these circumstances can result in composite failure [25]. The 40 wt.% composition of the fibre has the highest maximum water absorbed. The fibre content contributes to its absorptivity rate. At the beginning, it absorbs water at an increased rate before it attains the maximum, the rate drops drastically until reaches saturation point. The 40 wt.% of the fibre attains saturation earlier than the rest specimen.

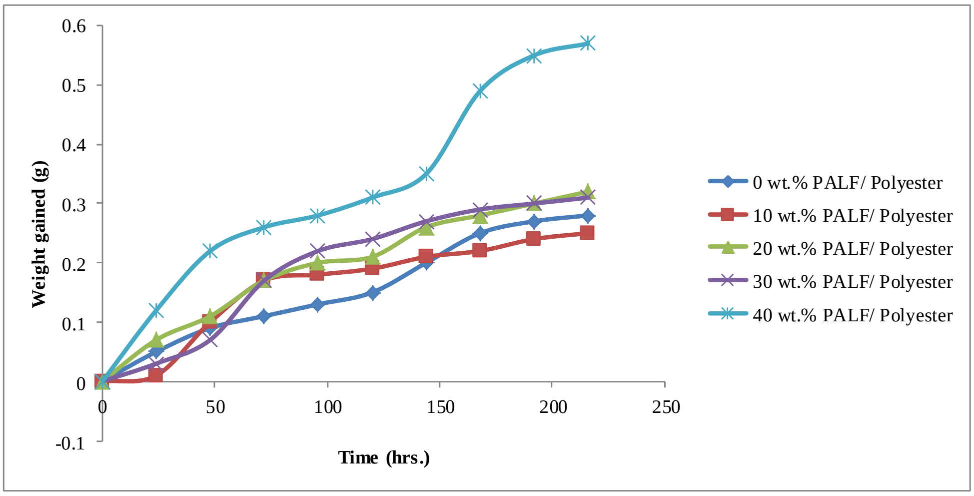

Figure 8. *Water absorption curve for neat polyester and PALF/ Polyester composites*

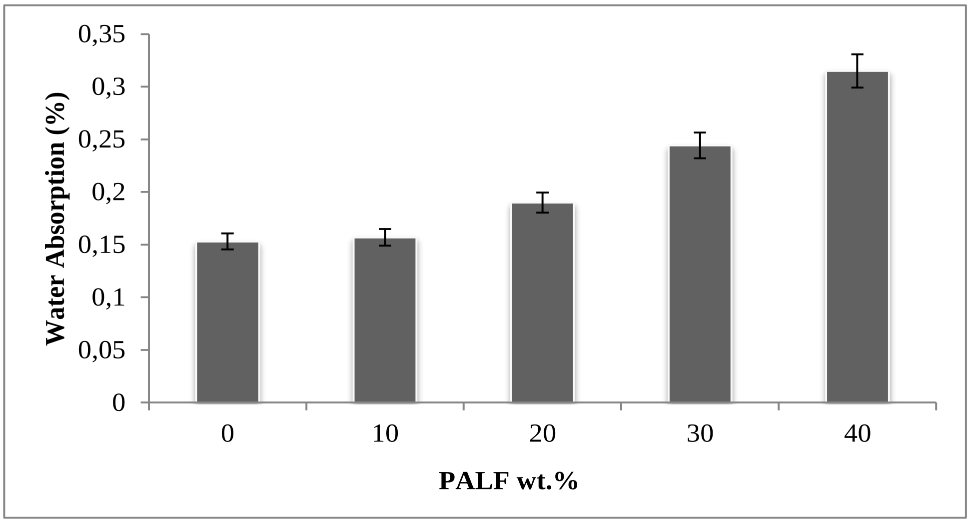

Figure 9. *Variations of water absorption behaviour of neat polyester and PALF/Polyester composites*

A flowchart showing the extraction and development of polyester/PALF composites is presented in Figure 10.

Conclusion

The results of this study showed that a useful composite with good properties could be successfully developed using treated pineapple leaf fibre as reinforcing agent for polyester matrix. The following conclusions can be drawn:

1. The ultimate tensile strength and the young's modulus of elasticity of PALF/Polyester composites increase linearly with increase in the fibre weight fraction.

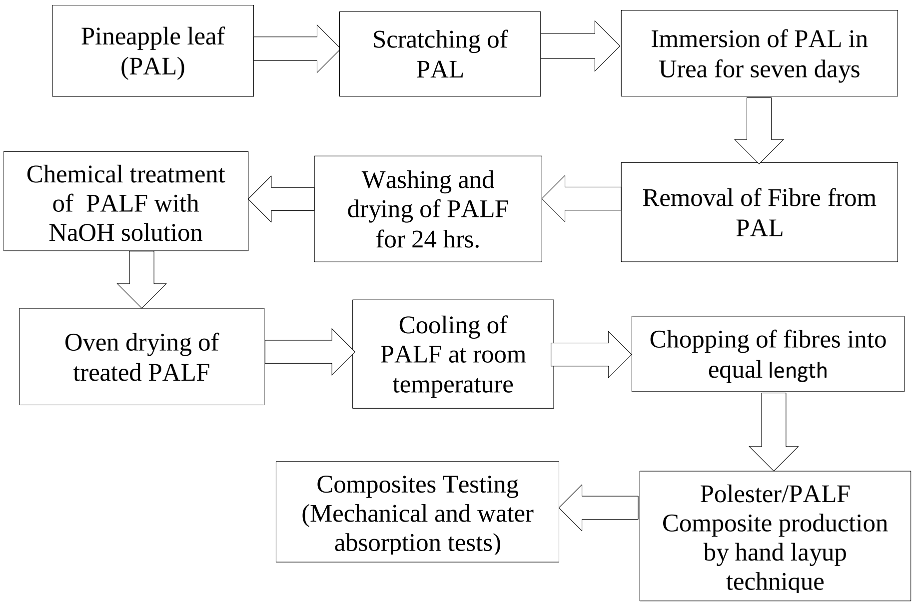

Figure 10. *Flowchart showing the extraction of PALF and development of Polyester/PALF Composites*

2. There was reduction in the percentage elongation of PALF/Polyester composites and the fibre weight fraction increases
3. The optimum flexural strength and flexural modulus were obtained at 20 wt.% PALF while the optimum hardness value was obtained at 30 wt.% PALF.
4. The amount of water absorbed by the composites increases with increase in the PALF weight fraction.

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