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Effect of Sodium Hydroxide Treatment on the Mechanical Properties of Crushed and Uncrushed *Luffa cylindrica* Fibre Reinforced rLDPE Composites

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***Abstract*—**Sustainability and eco-friendly requirement of engineering materials are sort for in recent times, thus giving rise to the development of bio-composites. However, the natural fibres to matrix interface interactions remain a key issue in getting the desired mechanical properties from such composites. Treatment of natural fibres is essential in improving matrix to filler adhesion, hence improving its mechanical properties. In this study, investigations were carried out to determine the effect of sodium hydroxide treatment on the tensile, flexural, impact and hardness properties of crushed and uncrushed *Luffa cylindrica* fibre reinforced recycled low density polyethylene composites. The LC (*Luffa cylindrica*) fibres were treated with 0%, 2%, 4%, 6%, 8% and 10% wt. sodium hydroxide (NaOH) concentrations for a period of 24 hours under room temperature conditions. A formulation ratio of 80/20 g (matrix to reinforcement) was maintained for all developed samples. Analysis of the results showed that the uncrushed luffa fibre samples gave better mechanical properties compared with the crushed luffa fibre samples. The uncrushed luffa fibre composites had a maximum tensile and flexural strength of 7.65 MPa and 17.08 Mpa respectively corresponding to a young modulus and flexural modulus of 21.08 MPa and 232.22 MPa for the 8% and 4% wt. NaOH concentration respectively. Results obtained in the research showed that NaOH treatment with the 8% NaOH concentration improved the mechanical properties of the LC fibre reinforced composites when compared with other NaOH treatment concentration values.

***Keywords*—**Flexural strength, LC fibres, LC/rLDPE composite, Tensile strength.

I. Introduction

THE non biodegradability of synthetic polymer composites and its effect on the environment poses much concern to scientific researchers in recent times. Recycling such polymers such as low density polyethylene (LDPE) and reinforcing them with bio-fibres to form such composites will put such polymers to effective use when they are discarded by consumers. Certain components make the reuse and recycling of polymers quite difficult, to an extent that direct disposal in dump or incineration is preferred [1], [2], however, the effect of synthetic polymers on the eco-system makes such means of disposal not to be desirable [3]. These problems which have lead to scientific research seeking alternatives to replace traditional polymer composites with substitutes having lesser environmental impact are referred to as "eco-composites", "green composites" [3], [4] or bio-composites.

In bio-composites, interfacial adhesion between the reinforcement and the matrix is usually weak as a result of the hydrophilic nature of the fibre and the hydrophobic nature of the matrix, hence the need for chemical modification of the fibre surfaces. Literatures have recorded that sodium hydroxide (NaOH) treatment also known as mercerization of fibres reduces the moisture absorption, poor wettability characteristic and enhances the mechanical properties of green composites [2], [5]. Chemical modification of the luffa fibres enhances the flexural strength and modulus of composites and appropriate alkali treatment is a key technology for improving mechanical properties of cellulose-based fibre composites [6], [7].

The applications of green composites are diversified into the engineering end uses mainly for non structural applications such as interior automobile components [8], [9] packaging materials [4], [8] building materials [10]–[11] and insulation [12]. Several authors have reported that chemical treatment of natural fibres using NaOH cleans fibre surfaces, promotes interfacial bonding and improves the mechanical properties of composites developed from such treated natural fibres [13]-[16]. However, an understanding of the proper amount of NaOH concentration needed to yield better desirable mechanical properties for such natural fibres is necessary.

This paper describes the preparation of recycled low density polyethylene composites reinforced with luffa cylindrica fibres. The mechanical properties of the untreated and NaOH treated reinforced fibre composites and the effects of various NaOH concentrations and fibre orientation (crushed and uncrushed state) were studied, analysed and discussed.

II. Experimental Method

A. Luffa Fibre Preparation

In this research, *Luffa cylindrica* was used as the reinforcement material. The choice of this natural fibre is as a result of its biodegradability, abundant availability and its physical fibrous interlocking nature. *Luffa cylindrica* used in the research was obtained from farms in Osara, Kogi State, Nigeria. *Luffa cylindrica* had lengths between 300 mm to 450 mm and a width variation of 180 mm to 377 mm when cut open.

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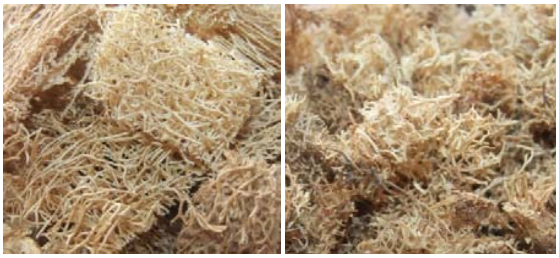

(a) (b)

Fig. 1 (a) Uncrushed LC fibre (b) Crushed LC fibre

Seeds in *Luffa cylindrica* (LC) were removed and clean mat fibres were cut to approximately 25 mm X 25 mm, length by breadth. Sodium Hydroxide solution for the 2%, 4%, 6%, 8% and 10% wt. concentration were prepared using distilled water and NaOH pellets. For the 2% wt. concentration, 2 g of NaOH was weighed using a digital weighing balance and dissolved in 100 mL of distilled water which is equivalent to 100 g. The formula that was used to attain the weight of the NaOH pellet dissolved for all the desired concentrations is stated in (1). For the 4, 6, 8 and 10% wt. concentrations, 4 g, 6 g, 8 g and 10 g of NaOH were dissolved in 100 mL of distilled water respectively.

$$\%\ by\ mass = \frac{mass\ of\ NaOH}{mass\ of\ distilled\ water} X\ 100 \qquad (1)$$

The volume of distilled water that was used for each batch treatment was 1600 mL. The fibres were soaked in the prepared solutions for a period of twenty four hours after which they were removed and thoroughly rinsed until a neutral pH of the rinsing solution was attained. A pH meter was used to determine the pH value of the solution after rinsing and the LC fibres were dried under direct sunlight. Some of the treated and untreated luffa samples were crushed using a jaw crusher. 20 g of the crushed and uncrushed *Luffa fibres* were each weighed, labeled and stored appropriately. Fig. 1 shows the picture of the uncrushed and crushed samples of *Luffa cylindrica* fibres.

B. Recycled Low Density Polyethylene (rLDPE)

The choice of recycled low density polyethylene (rLDPE) as the matrix material for the composite development is as a result of its mass availability as waste in the environment, its unfavourable effect as relating to non-biodegradability and the sustainability requirement of materials sort for in recent times. Low density polyethylene can be recycled to yield a variety of bulk physical properties and possesses flexible reprocess ability. The LDPE used in this research were transparent waste rolls (without ink printings) used for sachet water packaging. The waste rolls were obtained from Yus-Bol poly products in Barnawa, Kaduna State, Nigeria. Samples of the waste LDPE were cleaned and cut to varying but small sizes before the compounding.

C. LC/rLDPE Composite Development

The composites were developed at the Nigeria Institute of Leather and Science Technology, Samaru-Zaria, Kaduna State, Nigeria. The samples were compounded using a two roll mill manufactured by Reliable Rubber and Plastic Company, North Bergen, New Jersey, U.S.A. The formulation of 4:1 (matrix to fibre ratio) was maintained for all developed samples. Composites with reinforcement weight fraction between 20 g and 30 g (20% to 30%) exhibits better mechanical properties [13]. The LC fibres and the waste LDPE were then compounded on the mill at 150^{o}C. The mix was placed in a metallic mould of dimensions 110 x 110 x 5 mm and cured on a hydraulic press at a temperature of 150^{o}C at 13.7895 MPa for a period of 3 minutes. A foil paper was placed in the metallic mould to aid the ease of removal of the developed composite from the mould after the curing process.

(a) (b)

Fig. 2 (a) some of the cut samples (b) some of the developed composite

The LC/rLDPE composites were then cut to dumb bell and straight bar shapes for the various mechanical tests. Fig. 2 shows pictures of the developed composite and the cut samples. The dumb bell shape samples were cut to a dimension of 100 x15 x 4mm and a 40 x 10 mm guage length by width, while the flat bar shapes for the flexural test were cut to a dimension of 100 x 30 x 4 mm.

D. Tensile and Flexural Test

The tensile test was carried out using a motorised automatic recording tensometer manufactured in U.K. by Monsanto and is of the type 'w' with serial number 9875. The graph obtained from the test was analysed, the maximum force obtained was noted and used to calculate the ultimate tensile stress (UTS).

The 3 – point flexural bend test was carried out using a universal materials testing machine of 100 KN capacity. A range of 60 mm was used, with a 20 mm overhang on both sides of the support. The expressions used in obtaining the values of the flexural strength, modulus and the surface elongation at break are stated in (2)-(4):

$$\sigma_f = \frac{3FL}{2bH^2} \qquad (2)$$

$$Ef = \frac{L^2F}{4bH^3w} \qquad (3)$$

$$\varepsilon = \frac{6wH}{L^2} \qquad (4)$$

σ_f = flexural strength (MPa); E_f = flexural modulus (MPa); ε_f = surface elongation at break; F = maximum load (N); L = range (mm); H = thickness (mm); b = width (mm); w = deflection (mm).

The hardness test was performed using a durometer manufactured by Francisco Munoz Irles, C.B., Espana with model number 5019 and serial number 01554. The durometer values range from 0 (full penetration) to 100 (no penetration). This test was performed in accordance with the ISO 868.

The charpy v-notch test was performed on the developed composites cut to size 80 x 10 x 4 mm in accordance with one of the specimen sizes specified by ISO 179 for charpy impact tests. The notch was cut to 45° at 2 mm depth across the longer part of the specimen. The energy of the hammer used was 15 joules with a pendulum speed of 2.887 m/s. The charpy impact testing machine used in this research has its serial number as 412-07-15269C, manufactured by Norwood instruments limited, Great Britain.

III. Results And Discussion

Table I shows the results of the mechanical tests performed on the LC/rLDPE composites. All tests were performed at room temperature conditions.

TABLE I
RESULTS FOR THE MECHANICAL TESTS

Specimen (NaOH Concentration)	Tensile Strength (MPa)	Flexural Strength (MPa)	Young Modulus (MPa)	Flexural Modulus (MPa)	Shore-D Hardness	Charpy Impact Energy (J)
Crushed Sample						
0%	7.2035	16.9900	15.8912	642.31	80.00	1.70
2%	6.6920	14.4300	18.9844	493.75	84.00	4.35
4%	4.5455	12.0400	15.0017	562.78	80.67	0.90
6%	4.7579	9.0800	15.7065	300.27	82.33	3.15
8%	5.5269	13.2900	13.2065	195.60	77.33	2.20
10%	3.5877	16.2300	4.7551	284.24	73.00	1.65
Uncrushed Sample						
0%	7.2098	16.0700	19.3812	216.94	84.67	6.20
2%	6.9636	10.6100	15.4747	352.23	68.67	6.35
4%	5.5385	17.0800	12.0586	232.22	79.66	1.70
6%	5.7919	8.7000	13.6441	705.86	77.00	1.75
8%	7.6531	14.6900	21.0829	249.39	85.33	2.00
10%	5.1620	7.0200	14.7066	183.14	85.33	1.20

Fig. 3 shows a graphical illustration of all tensile values obtained from the test for the crushed and uncrushed LC fibre samples. The results attained shows that for all NaOH treatment values, the uncrushed sample exhibited better tensile strength characteristic compared with the crushed LC fibre samples. The uncrushed LC fibre composite gave the optimum tensile strength with a value of 7.6531 MPa corresponding to the 8% wt. NaOH treated fibre. The untreated fibre however recorded the highest tensile strength of 7.2035 MPa for the crushed LC fibre composite. This case of the untreated fibre having higher tensile strength than all other treated fibres is similar to the result obtained by [17] in a research on the properties of sugar cane/polyvinyl chloride composites (SB/PVC) subjected to various chemical treatments. It was that the untreated SB/PVC composite showed a higher tensile strength compared with other chemically treated SB/PVC composites.

It is reported that 5% NaOH treated natural fibre reinforced composites have better tensile strength properties than 10% NaOH treated composites [18] which confirms the results obtained in this research when compared with 4% wt. and 10% wt. NaOH treated LC fibre composites. This is because excess delignification of the LC fibre occurs at higher alkali concentration, resulting in weaker or damaged fibres [19] and hence a drastic decrement in the tensile strength of composites after a certain optimum concentration is attained [15]. This statement made by [15] confirms the result as illustrated in the graph of Fig. 3 which shows a drastic drop in the tensile strength after an optimum NaOH concentration value of 8% was attained for the NaOH concentration range of 0 to 10%. The closeness of the tensile strength values of some of the treated LC fibre composites when compared with the untreated LC fibre composite is confirmed by reports made by [20] who reported that the values obtained in their research on the effects of alkali treatment on curaua fibre green composites are almost equal to that of the untreated fibre and that the tensile strength of the fibre treated with15% NaOH concentration was lower than that of the untreated fibre composites. The reason for such was as a result of the loss of the crystalline structure by the cellulose molecular microfibrils during excess alkali treatment [16]. The loss of the crystalline structure after alkali treatments may be due to partial conversion of cellulose I into cellulose II which occurs during mercerisation [21], [22].

Both the crushed and uncrushed fibre samples indicated that treating the luffa fibres with 10% wt. NaOH concentration gives the least tensile strength. This confirms the assertion made by studies stating that at 10% NaOH concentration treatment of natural fibres, excess delignification occurs, making the fibre to become weaker [23]. Also to further confirm this, it is reported that 9% NaOH concentration treatment on kenaf fibres was too strong and may damage such natural fibres resulting in lower strengths of their corresponding composites [24]. It was noted during the tensile

test that the LC/rLDPE composites failed by tearing and no complete interfacial failure was observed in any of the samples. This indicated that for all the samples both treated and untreated, the adhesion between the fibres and the polyethylene matrix was quite strong. The tensile strength of 10% wt. alkaline treated fibre composites is nearly equal to that of untreated fibre composites [16], however, alkali treated fibres with of 10% wt. NaOH has much lower tensile strength than that of the untreated fibres [16], [17].

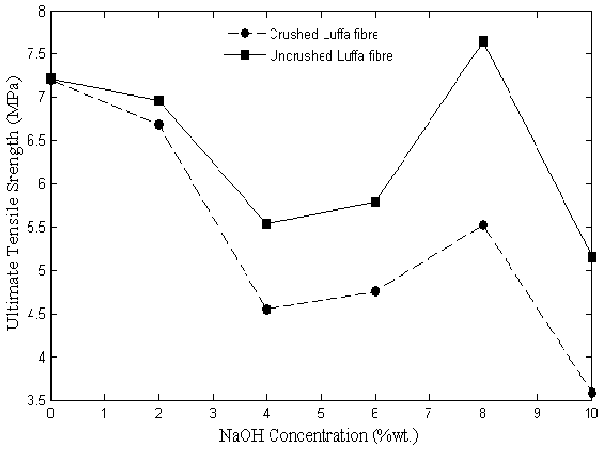

Fig. 3 Graphical illustration of the tensile strengths of the LC/rLDPE composite in relation to NaOH concentrations by weight

The result as presented in Table I show that the treatment of natural fibres with NaOH solution had effects on the mechanical properties of the developed composite. The tensile strength of the LC/rLDPE composite obtained in this research did not decrease or increase proportionally with increasing NaOH treatment concentration values. Instead, the tensile strength decreased and increased corresponding to varying concentration values as illustrated in the graph of Fig. 3. Considerable decrease in the tensile strength of all the crushed LC fibre composites when compared with the uncrushed LC fibre composite is noticed from the Fig. 3 that decrease in tensile strength and young modulus are probably due to decrease in the degree of crystallinity and crystallite orientation [25], [26]. Also, chopped *Luffa cylindrica* fibre reinforced composites results in lower tensile strength [27]. Improvement in tensile properties lower NaOH treatment when compared with 10% NaOH treated natural fibre reinforced composites is higher because at higher alkali concentration, excess delignification of natural fibres occurs resulting in a weaker or damaged fibre [15].

The flexural strength for the crushed fibres as illustrated in Fig. 4 decreased with increasing NaOH concentrations from the 0% wt. to the 4% wt. and began increasing from the 8% to the 10% wt. The flexural strength of the uncrushed fibres had alternating increment and decrement characteristic for increasing NaOH concentrations and had its optimum flexural strength with the 4% wt. NaOH treatment corresponding to a value of 17.08 MPa. The flexural strength of bio-composites depends on the alignment of the fibres and areas which are rich in resin [28], thus justifying the low flexural values obtained in the crushed LC fibres composite compared with the result obtained for the uncrushed LC fibre composites. Treatment of natural fibres with NaOH enhanced their flexural properties [29], [30]. The enhancement in the flexural properties of the treated fibre is due to the improvement in the fibre to matrix interaction [15].

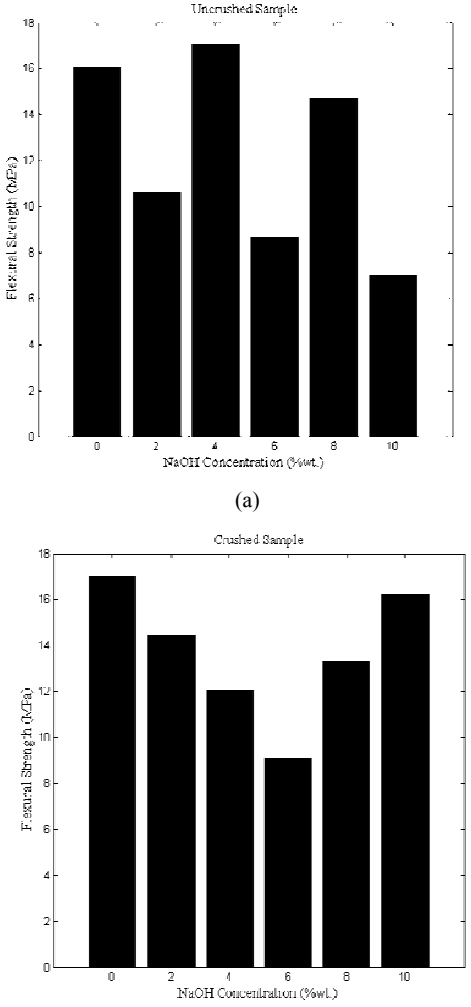

Fig. 4 Flexural Strength Chart in relation to the NaOH concentrations for the (a) uncrushed sample (b) crushed sample

From the Table I, it is seen that the LC fibre composite with 2% wt. NaOH concentration treatment has the optimum impact energy absorption values of 4.35 J and 6.20 J corresponding to the crushed and uncrushed fibres respectively. Increasing the fibres reinforcing percentage will increase the impact resistances of fibre reinforced composites [31], [32]. The variation in the impact properties of short luffa fibres exhibited scattered results and therefore a clear trend as regards their relationship with the chemical treatments of the fibres cannot be established [33]. A large variation of the fibre

diameters existed and such variations were expected from natural fibres thus contributing to the fluctuations exhibited by the fibres as well as their composites [34].

In relation to the hardness property of the LC/rLDPE composites, the composite with 2% wt. NaOH treatment gave the optimum shore-D hardness with a value of 84 for the crushed sample and the 8% and 10%wt. NaOH treated composite gave the optimum average shore-D hardness value of 85.33 for the uncrushed sample. Fig. 5 illustrates the hardness values of the developed LC/rLPDE composites compared with certain known polymers. From the chart in Fig. 5, the developed composites can satisfactorily substitute most of the stated polymers in applications where the hardness property is desired.

Conversions carried out using the chart in Fig. 5 is only an approximate estimate and are not considered as an exact value during conversions.

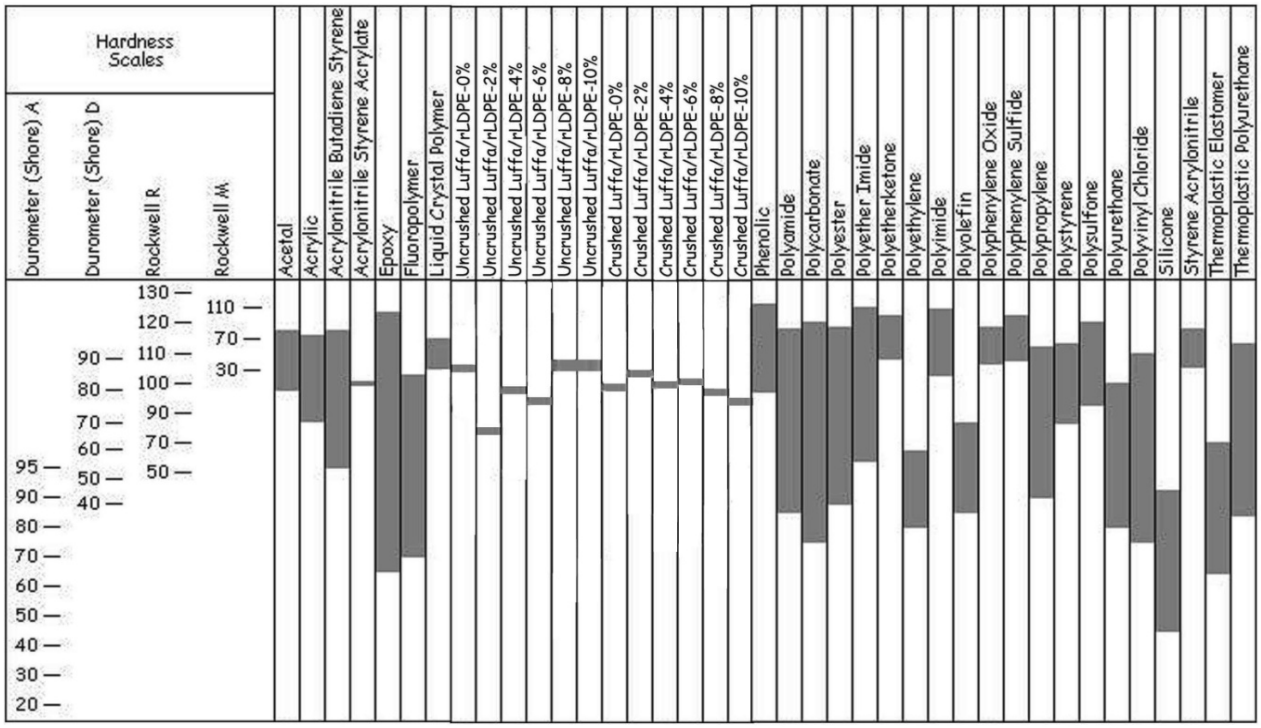

Fig. 5 A comparison chart showing the hardness of the LC/rLDPE composite and other polymers

IV. Conclusion

The treatment of the LC fibres modifies the fibres adequately causing a variation in the tensile and flexural properties of the LC/rLDPE composites in relation to the NaOH concentrations. The tensile and flexural strengths has its values dependent on varying NaOH concentration values, therefore no particular NaOH concentration value can be used to attain optimum values for all mechanical parameters in the crushed and uncrushed fibre state. However, the LC/rLDPE composites whose LC fibres were treated with 8% NaOH concentration gave better mechanical properties and therefore is considered a better treatment concentration value in the range of 0% to 10% wt. for improving the mechanical properties of composites reinforced with LC fibres. In relation to the fibre orientation, the uncrushed LC fibres exhibited better mechanical properties and they can conveniently replace certain synthetic polymer composites applied in the manufacture of automobile and aircrafts interior components. If the crushed LC fibre is desired to be used, the weight fraction has to be increased to enhance the mechanical properties of the composite.

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