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CHARACTERIZATION OF RECYCLED LINEAR DENSITY POLYETHYLENE/*IMPERATA CYLINDRICA* PARTICULATE COMPOSITES

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Abstract. Water-sachets made from low density polyethylene (LDPE) form a bulk of plastic wastes which creates environmental challenges, while certain species of plants like *Imperata cylindrica* constitute large portion of weeds on farm lands. As a technological approach to the reduction and utilization of these materials, composites of *Imperata cylindrica* (IC) particulate and synthetic polymer (from recycled waste water-sachets) were produced and evaluated for several mechanical and physical properties. The production of the composites and testing were done using the standard methods available in the literature. The results showed an increase in tensile modulus, hardness, impact strength, and water absorption of the composite in comparison with unreinforced polymer, as the IC particulate loading increased from 5 wt% to 30 wt%. However, there was a decrease in tensile strength, percentage elongation at break and density of the composite as the particulate loading increased from 5 wt% to 30 wt%. The combination of the recycled waste water-sachets and IC particulate is really promising for composites development. This creates opportunities to reduce LDPE wastes and add economic importance to an otherwise agricultural menace. It will mean creating an economic value from "wastes".

Keywords: mechanical properties; physical properties; *Imperata Cylindrica* (IC); particulate; waste water-sachets; composites and recycled linear low density polyethylene (RLDPE).

1. Introduction

The development of composite materials, particularly natural fibre composites, has become increasingly popular. The volume and number of applications of composite materials have grown steadily, reaching to and conquering new markets. According to a market report published by Lucintel [1], the future of natural fibre composites market looks attractive with opportunities in the automotive as well as building and construction industries. Modern composite materials constitute a significant proportion of the engineered materials market ranging from everyday products to sophisticated applications. The efforts to produce economically attractive composite components have resulted in several innovative manufacturing techniques currently being used in the composites industry [2]. These composite materials are sometimes produced using waste resources. The fact that natural resources are ever depleting calls for more responsible and efficient use of the available scarce resources. Besides, creating products from "waste" will really add value and help with environmental challenges posed by the enormous waste being generated. In many countries in Africa, potable water is being packed with sachets made from linear density polyethylene (LDPE). This has really become a big business in many cities. As a result of increasing demand for the packed water, there has been a rise in the amount of waste water-sachets generated. These empty sachets often end up thrown away on the streets creating large amount of non-biodegradable waste. Responsible utilization of these wastes will really be an advantage. The water-sachets clog mini-water ways, thereby creating a perfect breeding habitat for mosquitoes that are responsible for spreading malaria parasite, which is a major cause of illness on the African continent. Eventually, the water-sachets find their way to larger bodies of water such as oceans and seas and pose a serious threat to aquatic life, as these wastes can be around for many years because of their non-biodegradable nature. However, if the water-sachets are burnt, the emissions from the burning process severely pollutes the air and also contribute to the greenhouse effect, which is responsible for the global warming that the earth currently experiences as a result of the depleting ozone layer. There is, therefore, a need for a responsible handling of these wastes. One of such efforts targeted at utilizing the waste water-sachets is by incorporating natural fibres into them to produce a usable composite materials. Natural fibres could serve as viable and abundant alternatives to the expensive and non-renewable synthetic fibres as reinforcement in thermoplastic composites. These types of fibres present many advantages compared to synthetic fibres, such as low tool wear, low density, cheaper cost, availability and biodegradability [3, 4]. One of such natural

Figure 1. Ground IC.

Figure 2. Waste Water-Sachets.

Figure 3. Pulverized Water-Sachets.

fibres is *Imperata cylindrica*. It is an aggressive and difficult weed to control due to its short growth cycle. It is abundant, yet unsuitable for grazing animals and lacks a good commercial value [5]. When fully mature, its overall nutrient decline and its sharp pointed seeds and tangled awns may injure animals and humans [6]. They also act as a host for pathogens that affect the yield of some food crops [7]. However, *Imperata cylindrica* possesses good stiffness properties, which, if incorporated in a matrix, can enhance the composite rigidity. Hence, *Imperata cylindrica* is proposed as a fibre reinforcement for recycled water-sachets to produce a thermoplastic composite, thereby increasing its economic importance and reduce the environmental challenges posed by improper handling of waste water-sachets. This study, therefore, examined some mechanical and physical properties of recycled water-sachets/*Imperata cylindrica* particulate composite to determine its viability for engineering applications.

2. Materials and method

The part of the *Imperata cylindrica* (IC) that was used for this study is the stem and they were obtained from Pilla village in Makurdi area of Benue State. The waste water-sachets were gathered from the campus of the University of Agriculture Makurdi, Benue State.

2.1. Polymer and fibre processing

The *Imperata cylindrica* stems were harvested and sun-dried for two weeks. Subsequently, the finer strands of the stems were handpicked and ground (see Figure 1). The grounded particles were then filtered through a sieve of a pore size of 300 microns. The waste water-sachets (see Figure 2) were thoroughly washed, dried and pulverized at Goshen Plastics Industry, Makurdi (see Figure 3). These pulverized waste water-sachets will be referred to as recycled low density polyethylene (RLDPE) henceforth.

2.2. Composite preparation

The IC particulate and the RLDPE were weighed to get the required weight using an electronic weighing balance (Ohaus Adventurer Pro Analytical balance). The IC particulate and the recycled polymer were mixed such that the particulate weight ratio in the matrix varied from 5 wt% to 30 wt% in steps of 5 wt%. The mould was preheated at 100 °C. Half of the RLDPE was added to the mould because the cavity of the mould could not accommodate the whole mass of the RLDPE in an un-melted state. After one minute, the IC particulate was added to the mould and after that, the other half of the RLDPE was also added. The combined IC particulate and RLDPE were then heated in the Aluminium mould at a temperature of 150 °C for 15 minutes, during which the RLDPE showed a reasonable fluidity and the blend was thoroughly mixed to ensure homogeneity. The heating continued for another 5 minutes after which the mould was removed from the heat source and compressed using a 5tonnes hydraulic jack (see Figure 4). It was then allowed to cool at a room temperature until the composite took the shape of the mould cavity, after which the composite sheet ($295 \times 210 \times 5$ mm) was removed from the mould. Heating was carried out using a QASA (QSG-505G) gas cooker.

2.3. Composite characterization

The IC particulate-reinforced plastic sheet was retrieved from the mould and cut into test specimens. Characterization of the composites was achieved by mechanical testing. Some physical properties of the materials were also examined.

Figure 4. Compression of the mould and content.

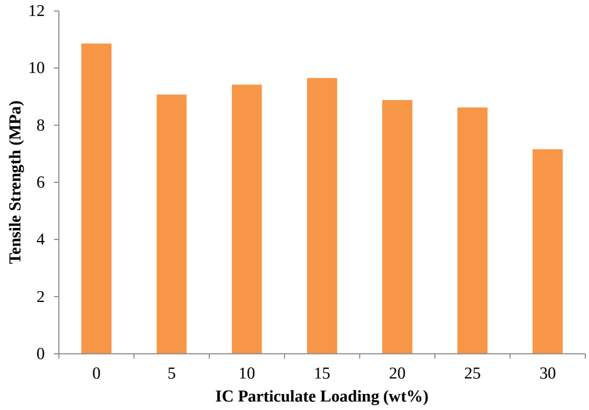

Figure 5. Tensile strength at varying IC particulate loading.

2.3.1. Mechanical properties

Tensile test was carried out using the Instron 3369 (Universal Testing Machine) according to ASTM D 638, to determine the tensile strength, tensile modulus, and elongation at break of the materials. The test specimen had a dumb-bell shape with a gauge length of 30 mm, grip width of 15 mm and thickness of 5 mm. Specimens were placed in the grips of the universal tester and pulled at a crosshead speed of 5 mm/min until failure. The hardness of the materials was measured using a Computerized Micro-Vickers Hardness Tester (MV-1 PC) with a load of 300g according to ASTM E 384, which is a standard test method for Vickers hardness testing of materials. The Vickers indenter produces a geometrically similar indentation at all test forces. The dimension of the hardness specimens is $40 \times 40 \times 5$ mm. The Charpy impact test was carried out to determine the impact strength of the composites according to ASTM D 6110, which is used to determine the resistance of plastics to a breakage by flexural shock produced by a pendulum type hammer. The dimension of the impact test specimens was $100 \times 10 \times 5$ mm. Three specimens from each of the materials were used for each of the tests.

2.3.2. Physical properties

Water absorption test according to ASTM D-570 was also carried out to determine the water absorption characteristic of the composite. Three samples from each of the materials, with dimensions $42 \times 12 \times 5$ mm, were cut, cleaned and weighed before immersion in distilled water at a room temperature. The specimens were removed from the water after 24 hours and the surfaces wiped off and weighed. The difference between the weight before and after immersion was noted. The water absorption was then calculated using

$$A = \frac{M_2 - M_1}{M_1} \cdot 100\,\%, \tag{1}$$

where M_1 is the initial mass in grams and M_2 is the final mass in grams.

The density of the composite was also determined by comparing the mass of a given specimen with its volume:

$$\text{density } (\varrho) = \frac{\text{mass } (m)}{\text{volume } (v)}. \tag{2}$$

The dimensions of the specimens used to determine the density was $50 \times 50 \times 5$ mm.

3. Results and discussion

3.1. Mechanical properties

3.1.1. Tensile strength

Figure 5 illustrates the average tensile strength of the composite produced at different IC particulate loadings as compared to the RLDPE. It showed that the RLDPE has an average tensile strength of 10.86MPa. It was observed that there was a decrease of 16.48 % to 34.07 % in the average tensile strength of the composite as the IC particulate loading increased from 5 wt% to 30 wt% compared to the RLDPE. Though, there was an increment of 6.39 % in the average tensile strength of the composite for particulate loading from 5 wt% to 15 wt%. The maximum average tensile strength of the composite is nevertheless still lower compared to that of the RLDPE. The decrease is due to the poor interfacial adhesion between the hydrophobic RLDPE and hydrophilic IC particulate. The Scanning Electron Microscope micrographs (see Figures 6 and 7) showed that while the IC particulates were fairly evenly distributed within the matrix, the agglomeration of the particulate observed, however, indicates a weak interfacial bonding. Poor interfacial adhesion acts as a stress concentration point upon an application of external forces leading to a premature failure due to a poor stress transfer from matrix to the fibre particulate. Higher tensile strength demonstrated by the neat RLDPE is due to the flexibility and plasticity of the RLDPE [3].

3.1.2. Tensile modulus

Figure 8 illustrates the average tensile modulus of the composite produced at different particulate load-

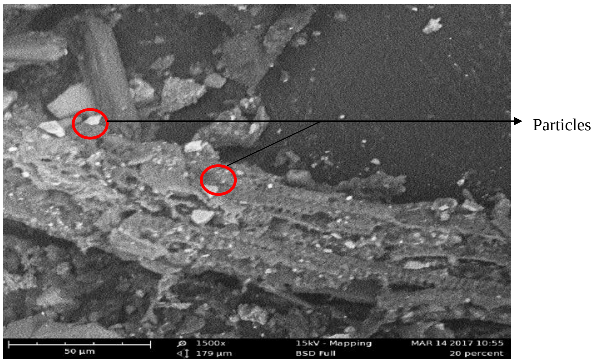

Figure 6. SEM Micrograph at 20 wt% IC Particulate Loading.

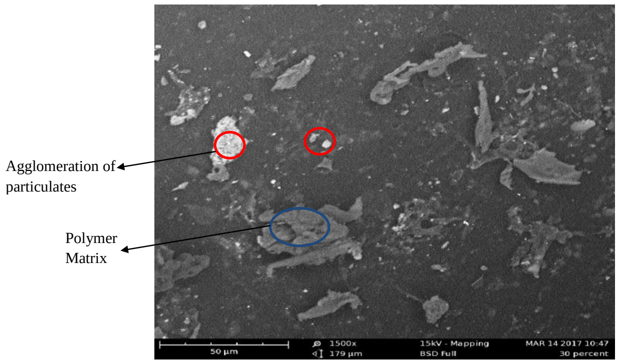

Figure 7. SEM Micrographs at 30 wt% IC Particulate Loading.

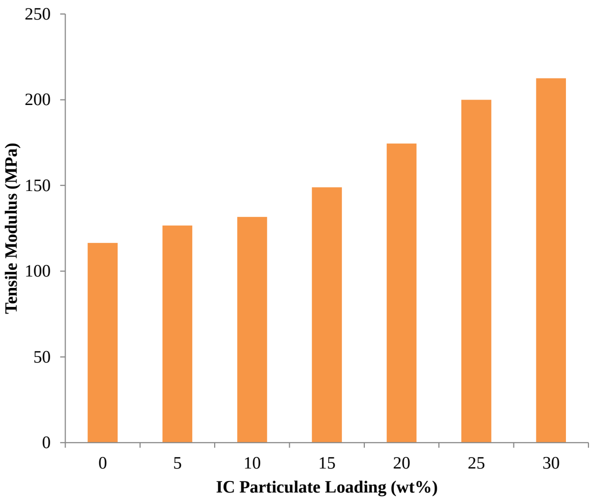

Figure 8. Tensile Modulus at varying IC particulate loading.

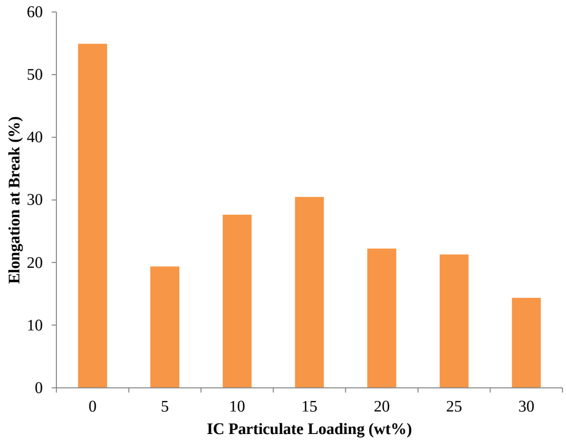

Figure 9. Elongation at break at varying IC particulate loading.

ings as compared to the RLDPE. It showed that the RLDPE has an average tensile modulus of 116.44MPa. It was observed that as the particulate loading increased from 5 wt% to 30 wt%, there was an increase of 8.78 % to 82.53 % in the average tensile modulus of the composites when compared to the RLDPE. As the IC particulate loading increased, the elasticity of RLDPE has been suppressed by the presence of the derived cellulose. The increment in the modulus is attributed to the decreased deformability of the interface between the IC particulate and the matrix material, which caused a reduced strain as the particulate loading increased, due to the rigidity of the material [3]. Then et al. [8] suggested that the enhancement in the tensile modulus is probably due to the fibres itself, which have a higher stiffness than those of the polymer.

3.1.3. Percentage elongation at break

Figure 9 illustrates the average percentage elongation at break of the composite produced at different cellulose loadings as compared to the RLDPE. It showed that the RLDPE has a percentage elongation at break of 54.93 %. It was observed that there was a decrease of 64.73 % to 73.84 % in the average percentage elongation at break of the composite as the IC particulate loading increased from 5 wt% to 30 wt% compared to the RLDPE. However, there was an increment of 57.31 % in the average percentage elongation at break of the composite for particulate loading from 5 wt% to 15 wt%. The maximum average percentage elongation at break of the composite is nonetheless still lower compared to that of the RLDPE. The increment noticed between 5 wt% and 15 wt% particulate loadings may be attributed to a better dispersion of the particles within the matrix. There was less agglomeration of the particles and so a slightly more strain at this range of particulate loading. However, as the IC particulate loading increased, the elasticity of the composite is suppressed by the presence of the increased derived cellulose. The reduction is attributed to the decreased deformability of a rigid interface between the IC particulate and the matrix material [3]. Liu et al. [9] reported that the decrease in elongation at break is due to the destruction of the structural integrity of the polymer by the fibres and the rigid structure of the fibres.

IC Particulate Loading (wt%)	**Impact Strength** (J)	**Hardness** (HV)
0	5.03	52.63
5	2.68	50.57
10	2.88	64.73
15	2.98	70.63
20	3.45	91.53
25	3.8	103.77
30	4.4	111.33

Table 1. Impact strength and hardness property in relation to IC particulate loading.

IC Particulate Loading (wt%)	**Water Absorption** (%)	**Mass** (g)	**Density** (g/cm^3)
0	4.64	10.69	0.855
5	6.81	10.66	0.853
10	7.11	10.34	0.827
15	7.19	10.01	0.801
20	7.86	9.88	0.791
25	13.66	9.86	0.789
30	15.47	9.77	0.782

Table 2. Water absorption and density in relation to IC particulate loading.

3.1.4. Impact strength

Table 1 illustrates the average impact strength of the composite produced at different particulate loadings as compared to the RLDPE. It showed that the RLDPE has an average impact strength of 5.03 J. Higher impact strength demonstrated by the neat RLDPE is due to the flexibility, plasticity, and less brittleness of the RLDPE, which allows it to absorb and distribute the impact energy efficiently [3]. There was an increase of 7.46 % to 64.18 % in the average impact strength of the composite as the IC particulate loading increased from 5 wt% to 30 wt%. Nevertheless, the maximum average impact strength of the composite at 30 wt% particulate loading was still 12.52 % lower when compared to that of the RLDPE. Considering the steady increment that was observed, up to 30 wt% loading of the IC particulate, it is possible that if the particulate loading increases beyond 30 wt%, the impact strength of the composite may eventually reach or even exceed that of the RLDPE at some point. The increment in the average impact strength may be attributed to the rigid interface between the IC particulate and the matrix material as the particulate loading increased.

3.1.5. Hardness property

Table 1 illustrates the average hardness values of the composite produced at different IC particulate loadings as compared to the RLDPE. It showed that the RLDPE has an average hardness value of 52.63. It was observed that as the particulate loading increased from 5 wt% to 30 wt%, there was an increase of 22.99 % to 111.53 % in the average hardness values of the composites when compared to the RLDPE. The increase in the hardness property observed with the RLDPE/IC particulate composite is a result of the hardness property of the IC particulate itself, which has been transmitted to the composite. The reduction in the hardness value at 5 wt% particulate loading may be as a result of a void in the composite [10].

3.2. Physical properties

3.2.1. Water absorption

Table 2 illustrates the average percentage water absorption of the composite produced at different IC particulate loadings as compared to the RLDPE. It showed that the RLDPE has a percentage water absorption of 4.64 %. It was observed that as the IC particulate loading was increased from 5 wt% to 30 wt%, there was an increase of 46.77 % to 233.41 % in the average percentage water absorption of the composites when compared to the RLDPE. This result is according to expectations, as composites with natural fibre reinforcement exhibit higher water absorption due to the inherent hydrophilic nature of the fillers [11, 12].

3.2.2. Density

Table 2 illustrates the average density of the composite produced at different IC particulate loadings when compared to RLDPE. It showed that the RLDPE has a density of 0.855 g/cm^3. It was observed that as the IC particulate loading was increased from 5 wt% to 30 wt%, there was a decrease of 0.23 % to 8.53 % in the average density of the composites when compared to the RLDPE. The decrease in the density observed with the RLDPE/IC particulate composite is as a result of the low density of the IC particulate itself, which has been transmitted to the composite. When a larger fraction of the RLDPE, which is of a higher density, is replaced by lighter particulates, the overall density of the subsequent composite is reduced, which is one advantage that natural fibre composites have over synthetic fibre composites [3] and other engineering materials.

4. Conclusion

In this study, RLDPE/IC particulate composites have been produced through a form of hand lay-up techniques and the mechanical and physical properties at 5 wt% to 30 wt% particulate loadings have been examined. The results from the tests carried out showed that the tensile modulus, hardness, impact strength and water absorption of the composite increased as the IC particulate loading increased from 5 wt% to 30 wt% respectively. Although, an increasing trend was observed for the impact strength as particulate loading increased up to 30 wt%, the value was still lower compared to that of the RLDPE. By increasing the IC particulate loading beyond 30 wt%, the impact strength of the composite may eventually reach or even exceed that of the RLDPE at some point. However, tensile strength, percentage elongation at break and density of the composite decreased as particulate loading increased 5 wt% to 30 wt% respectively. Although an increase in tensile strength and elongation was observed up to 15 wt% loading of the particulate, the maximum tensile strength and elongation of the composite at that loading was still lower than that of the RLDPE. The results obtained from the tests conducted showed that the composite can actually be adapted in some engineering applications particularly because of the positive indications observed regarding tensile modulus, hardness, impact strength and density. The combination of the recycled waste water-sachets and the IC particulate is really promising for a composite development. This creates opportunities to reduce LDPE wastes and add economic importance to an otherwise agricultural menace. It will mean creating an economic value from "wastes".

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