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Biodegradation of Luffa Fiber Reinforced Waste Polystyrene Foam Composite in a Natural Compost Environment

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ABSTRACT

Biocomposites are environmentally friendly because they easily biodegrade when compared to synthetic materials. They possess other advantageous properties such as abundance, low cost, light weight, low density, and high strength/weight ratio. This paper however presents the microbial degradation due to soil bacteria on luffa fiber polystyrene composite. Luffa cylindrica fiber was treated with 0.5 wt% sodium hydroxide and used as reinforcement in waste polystyrene foam. The loading of the luffa fiber was from 0 wt% (unreinforced polystyrene) to 50 wt%. The composite was buried for 22 weeks and effect of bacteria activity on the composites' weight loss studied. It was observed that degradation was highest (44.91 %) for composite with highest luffa fiber (50 wt%) while the unreinforced waste polystyrene had the lowest degradation of 1.35%. The microorganism identified in the soil was bacillus sp. which had a cell count of 4.0 × 10^7 CFU/gm. It can be concluded that reinforcing polystyrene foam with luffa, produces bio composites that are environmentally friendly.

1. INTRODUCTION

Biocomposites as an alternative to conventional synthetic composites are becoming attractive in recent years. This is because natural fillers which are abundant are incorporated or used as reinforcement in the synthetic polymers or matrix. The resulting biocompoites are not only cheaper, but possess valuable properties such as light weight, high strength to weight ratio, renewable, lower emissions of toxic fumes when incinerated, low hazard during manufacturing, and most importantly more biodegradable compared to purely synthetics composites (Bandyopadhyay-Ghosh and Ghosh, 2015; Pickering *et al*., 2016; Ghori *et al*., 2017). Natural fillers, however, have drawbacks, they have low dimensional stability, variable properties depending on source, specie or variety of the plant and compatibility issues with the synthetic matrix which they reinforce. This is because most bio fillers are hydrophilic while synthetic matrices are hydrophobic, thereby causing composite swellings and unsuitable mechanical properties (Ali *et al*., 2016). Mechanical properties of biocomposites can be improved if the morphology of the natural fillers is modified or treated (La Mantia and Morreale, 2011; Sanjay *et al*., 2017). Common treatments known to improve mechanical properties include alkaline, maceration, benzoate, saline isocyanate, corona as well as thermal treatment (Li *et al*., 2007; La Mantia and Morreale, 2011; Ponnusamy *et al*., 2019).

Problems posed by plastics cannot be overemphasized. They litter everywhere because they do not easily degrade, block drains, suffocate aquatic lives and when incinerated, they pollute the environment with toxic chemicals (Luchesea *et al*., 2018; Sessini *et al*., 2019). The increasing threat to the environment by plastics has made environmental pressure groups to seek support from scientists and Engineers to tackle these excessive carbon footprints. The production of biodegradable composites from natural fiber and synthetic fillers will not only increase the overall biodegradability of the synthetic filler but also reduce waste plastic accumulations and reduce the dependence on fossil fuels (Bonilla *et al*., 2013; Gonzalez *et al*., 2016). The biodegradation of the biocomposites by biological processes involves living organism such as bacteria, fungi and algae to breakdown the organic substances present in the composites into simpler and smaller structures such as carbon dioxides, water and methane as end products (Shah *et al*., 2008; Pelissari *et al*., 2019). The simpler end products are easily disposed with little environmental impact (Adamcova *et al*., 2017).

This research work therefore focuses on the study of biodegradation by burial method of a bio-composite formed from Luffa fiber and waste polystyrene foam. The soil organism was identified and degradation rate due to the organism was monitored and studied.

2. METHODOLOGY

2.1 Materials

The materials and reagents used in research include: waste polystyrene foam, luffa fiber, methylated spirit, distilled water, nutrient agar, wool, crystal violet, iodine, ethanol, safranin, paper towel, foil paper, and sodium hydroxide. The equipment/apparatus used were laboratory glass wares, staining rack, culture plates (petri plates), sterile syringes, forceps, wire loop, digital weighting balance, electric heating mantle, bunsen burner, incubator, autoclave, microscope, and humidity and temperature meter, farm land.

2.2 Methodology

Composite Preparation

Luffa fiber was first obtained, cut washed and dried before being treated with 10 wt% NaOH. It was then washed and dried in the oven at 60 ^oC for two (2) hours. The fiber was then used to reinforce waste polystyrene foam in a two (2) roll mill after which it was then compressed at 100 ^oC at 4psi. fiber loading (0 to 50 wt%) at an interval of 10 wt% used as reinforcement. Three (3) samples each of size 25 x 30 x 5 cm were cut, weighed and taken for biodegradation test using burial method.

Biodegradation Test Using Burial Method

In this research, a land space of 2 × 1 x 0.1 m at Kaduna Polytechnic Demonstration Farm, Kaduna was cleared. A mixture of soil samples taken from the cleared ground was then taken for microbial analysis. The composite samples were then buried at a depth of 5 cm maintained at an average temperature and humidity of 27 ^oC and 20% respectively by sprinkling water (Haider *et al*., 2018). The composite samples and burial site is shown in Plate 1. After seven days (a week), all samples were removed, washed, cleaned and dried in the oven at 60 ^oC and 4 hrs before calculating the weight loss given by (1):

$$\text{Weight Loss }(\%) = \frac{(\text{Mo} - \text{Ms})}{\text{Mo}} \times 100 \qquad (1)$$

where Mo is the initial mass of the samples and Ms is the mass of buried composite after reference days. The composite samples were then reburied into the soil for another week for the same weight loss to be calculated. These burial and weight loss calculation processes were continued for 22 weeks after which the samples were removed for morphology analyses.

Microbial Analysis of Soil Sample

Serial dilution method was used to prepare nutrient agar after which it was transferred into sterilized petri dish. The soil sample taken from the burial site was then plated and incubated for 24 hours after which the microorganism was identified with Celestron Compound microscope (model: CB200C). The microbial growth was counted and analyzed using equation (2). Coliform count between 20-200 is recommended and therefore was used in this study (Bio Resource, 2016).

$$\text{NCU(CFU/gm)} = \frac{\text{Number of Colonies Count (Average)} \times \text{Recip.of Dil.Factor}}{\text{ml plated}} \quad (2)$$

where CFU/gm is colonies forming units per ml, and ml plated used is 0.1 ml.

A smear and gram staining process were then carried out on the coliform unit. Shape and colour were observed under the microscope to identify the species of the bacteria present. The biodegradation analysis was carried out based on ASTM D6691 (2001) as adopted by Muller (2005).

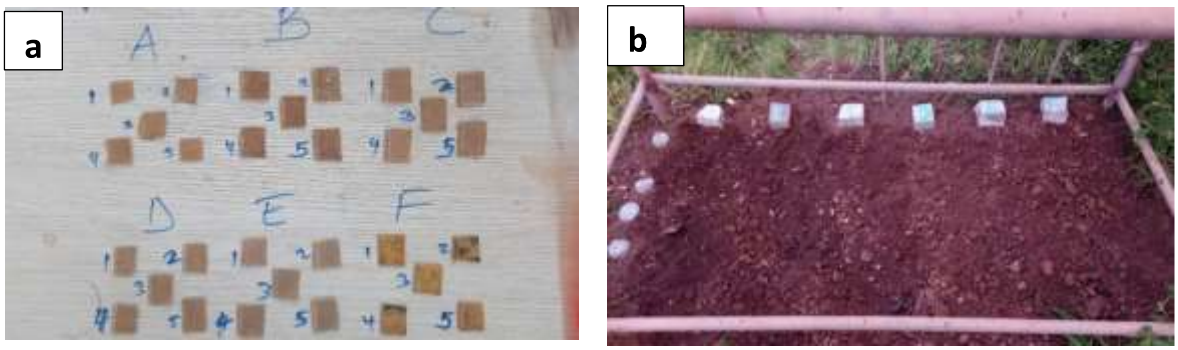


Plate 1: Image showing (a) Composite samples (b) burial site for the samples

3. RESULTS AND DISCUSSION

3.1 Biodegradation Analysis of the Composites.

Figure 1 shows the rate of biodegradation of the composite samples. It was observed that the un-reinforced composites which served as the control sample degraded by only 1.35% after 22 weeks. It had the lowest degradation rate among all the samples. Sample E (50/50) had the highest degradation rate (44.91 %) after 22 weeks because of its high natural fiber content. This is almost five times (5 x) the degradation at 11 weeks. Surface morphology (Figure 3) using image analyzer also confirmed that sample E (50 wt% luffa) had the highest integration with microbes after 22 weeks, hence highest degradation. It was generally observed that the degradation rate increased with increase in fiber content. This is in line with the result of Gomez and Michel (2013) and Bello *et al*. (2019) because of the biodegradable nature of natural fibers. This makes them attractive for application in production of bio degradable polymers (Lucas *et al*., 2008).

The sample degradation rate was further analyzed using Microsoft excel, the trendline was generated and fitted as summarized in Table 1. The samples degradation rate easily fitted into a polynomial model of order 3. Polynomial of order 3 suggests the degradation behavior will have a minimum and a maximum. The minimum at the initial degradation stage and the maximum is at the later stage of the degradation. This is evident in sample D and E (30 and 50 wt % luffa) with lots of cracks and pores (shown in red lines) due to microbial attack as seen in Plate 2 (Krauklis *et al*., 2019).

Table 1: Modelling of degradation rate of composite samples buried for 14 weeks

Samples	Equation	R^2
A	$y = 0.0027x^3 - 0.0389x^2 + 0.0437x - 0.6007$	0.9531
B	$y = 0.0043x^3 - 0.1581x^2 + 0.6719x - 1.364$	0.9830
C	$y = -0.0056x^3 - 0.1187x^2 + 0.7519x - 2.2371$	0.8915
D	$y = 0.0179x^3 - 0.3538x^2 + 0.5269x - 2.2393$	0.9958
E	$y = 0.031x^3 - 1.0894x^2 + 4.5807x - 6.0348$	0.9916
F	$y = -0.0239x^3 - 0.1772x^2 + 0.8758x - 4.8195$	0.9622

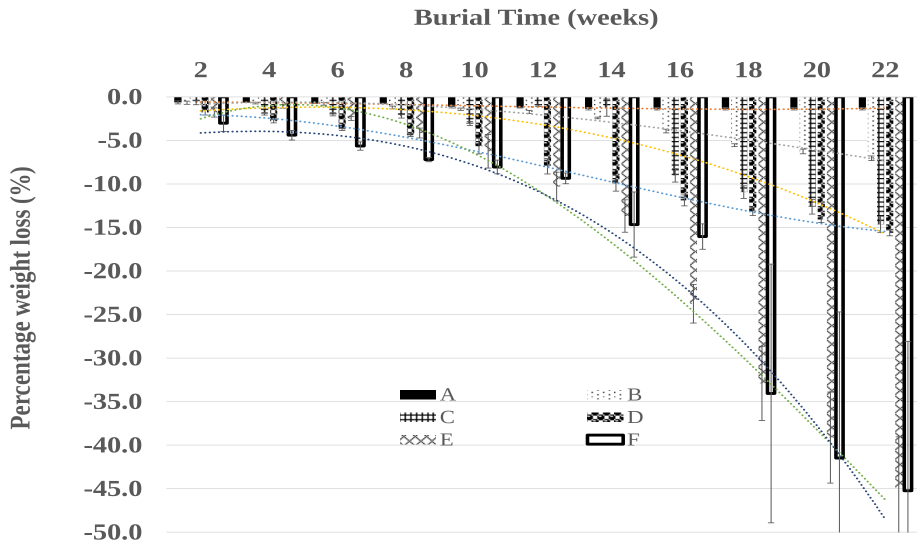


Figure 1: Degradation rate of the composites samples for 22 weeks

3.2 Microbial Count in the Soil

Table 2 shows the count of the coliform forming unit (CFU) observed in the plate of incubated soil sample collected from the sample burial site. The counts for serial dilution for 10^{-1} to 10^{-3} was neglected because the colonies were too numerous to count. The serial dilution for 10^{-4} was also neglected because of the wide variation in counts, therefore 10^{-5} serial dilution was used as suggested by Bio Resource (2016). The average total number of bacteria counted of the colonies forming unit was calculated to be 4.0×10^7 CFU/gm of soil.

Table 2: Quantification Number of Colonies Forming Unit (CFU)

Dilution Series	Plate	Number of Colonies Count	Average of Number of Colonies Count	Colony Forming Unit (CFU/gm)
10^{-1}	1	+++		
	2	+++		
	3	+++		
10^{-2}	1	+++		
	2	+++		
	3	+++		
10^{-3}	1	+++		
	2	+++		
	3	+++		
	1	48		
10^{-4}	2	63		
	3	90		
	1	34		
10^{-5}	2	41	40	4.0×10^7
	3	45		
	1	18		
10^{-6}	2	25		
	3	28		

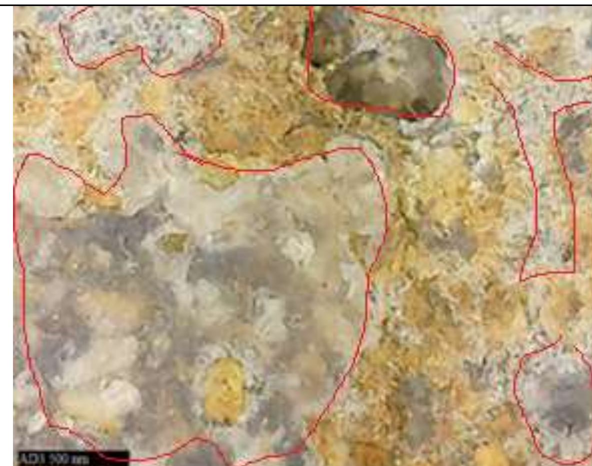
	Before burial	After 22 weeks burial
Unreinforced polystyrene foam (Sample A)		
30 wt% reinforced polystyrene foam (Sample D)		
50 wt% reinforced polystyrene foam (Sample F)		

Plate 2: Surface morphology of the biocomposites before and after 22 weeks

3.3 Identification of Microorganisms in the Soil Sample

The identification of the species of microorganisms in the soil sample was carried out under the microscopy observation using a Tutoy 1600X Zoom 8, digital biological endoscope. The type of microorganisms observed in the soil sample was gram positive bacteria, which showed the present of Bacillus because of its rod-like structure and purple color as shown in Plate 3.

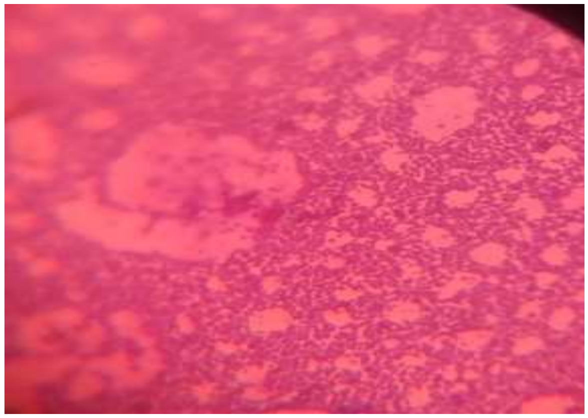


Plate 3: Rod like bacillus specie observed in the stained colonies

4. CONCLUSION

The following conclusions were drawn from this study.

1. The degradation increased with increase in fiber content as 50 wt% recorded the highest at 44.91 % while the lowest degradation of 1.35% was observed for the un-reinforced composite after 22 weeks.
2. The degradation rate followed mostly a polynomial model of order 3.
3. The microorganism responsible for the degradation behavior of the composite was the *bacillus* sp of bacteria.
4. The average coliform forming unit was 4.0×10^7 CFU/gm of soil.

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