Study of the Physical Properties and Biodegradability of Potato-Starch Based Plastics

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***Abstract* - Due to the exceptional growth of environmental menace pollution caused by the disposal of used plastics in the world today, there exist the needs to produce biodegradable plastics from cheap and renewable feed stocks. This research work focuses on the synthesis and characterization of potato starch based plastics (biodegradable) using polyvinyl alcohol (PVA) as cross linker. PVA was varied in mass ratios of 15, 30, 45 and 80% in the thermoplastic starch (TPS)/PVA blend. Mechanical properties (such as tensile strength, percentage elongation, young modulus) and specific gravity of the blends were studied. The results showed that 80% PVA plastic had the highest tensile strength, elongation and lowest young modulus of 384.47kPa, 347.27%, and 310.10kPa respectively. The specific gravity of the whole blends was 1.2. The elongation at break increases with increasing concentration of PVA, having the least value of 0% and highest value of 481.82% for 15 % and 80 % PVA plastic respectively. In addition, the results obtained showed increase in the values of the properties of the samples with respect to thermal conductivity, acid, base and water resistance with increase in composition of PVA. Biodegradability test was done via soil-burial method and the PVA/TPS blend was noted to be biodegradable.**

Keywords: Biodegradability, starch/pva blend, physical properties, water absorption resistance

I. INTRODUCTION

Plastics are cost-effective resources utilised for a wide variety of applications in industries such as surgery, packaging, catering, hygiene, agriculture, fishing, environmental protection, technical and other sectors. Features such as low-density, low cost, ease of processing and flexibility in design give plastics an advantage over other packaging materials.

Most synthetic polymers and plastics currently produced, are however, manufactured from petrochemical compounds and there is a growing global concern about the future economic sustainability of utilizing such non-renewable materials in such short-term applications. More essentially, conventional petrochemical-based plastics are not easily degraded in the environment due to their high molecular weight and hydrophobic behaviours. Subsequently, the disorder caused to the environments as a result of non-degradable materials in the ecosystems has prompted decision-makers and the plastics industry worldwide to ascertain and develop durable bio-based substitutes in an attempt to efficiently minimize the aftermath effect of waste plastics [9]. Among all the natural polymers utilised in producing biodegradable plastics, starch is of the highest interest owing to its inherent biodegradability in various environment, renewability, abundance and cost effectiveness [6]. Due to the fact that native starch is a multi-hydroxyl polymer, it is considered not a true thermoplastic [1]. But in the presence of plasticizers (e.g glycerol) and under shear it readily melted and flows, allowing for its use as an injection, extrusion or blow moulding material, similar to most conventional synthetic thermoplastic polymers [7].

Thermoplastic starch (TPS) is relatively new material for application as biodegradable plastic. In spite of these properties, thermoplastic starch still possesses some disadvantages when compared to most plastics currently in use which is mostly its water solubility and poor mechanical properties**.** As reported by [2], the water resistance of TPS may be improved by mixing it with biodegradable polymers. In this research paper, biodegradable composites of potato starch using polyvinyl alcohol as cross linker were synthesized and characterized. Mechanical properties (tensile strength, percentage elongation, young modulus) and specific gravity of the composites were studied. In addition, the thermal conductivity, acid, base and moisture resistance studies of the composites were also carried out. Moreover, biodegradation studies of the composites were also done using soil burial method.

II. METHODOLOGY

The sweet potatoes that were utilised for this work were obtained from Minna, Nigeria. The tubers were washed and rinsed with tap water. The potatoes were grated with a fabricated metal grater and thereafter filtered with a 75 µm sieve. The filtrate was allowed to settle in a closed system for a period of 5 hours which aids the coagulation of the starch components at the bottom of the system. The starch-free liquid was then decanted and the starch was rinsed with fresh tap water. The starch was dried at a temperature range of 80 - 100^{o}C for a period of 8 hours. An amount of starch, and glycerol were measured into a 1000 mL beaker. The mixture was mixed thoroughly and thereafter, PVA was poured into the starch-glycerol mixture (TPS). Six samples were made with various amount of PVA as shown in Table 1.

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Table 1: Composition of the Plastic Samples

Samples	TPS (g)		PVA (g)	PVA (%)
	Starch	Glycerol		
A	50	21.43	12.61	15
B	50	21.43	30.61	30
C	50	21.43	58.44	45
D	50	21.43	71.43	50
E	50	21.43	132.66	65
F	50	21.43	285.72	80

TPS/PVA blend was made into small shapes and then dried in a vacuum oven for 4 hours at a temperature range of 100 – 110^{o}C.

A. Characterization

Various characterization was done on the samples to ascertain their properties and its biodegradability.

B. Water absorption resistant

Water absorption, acid and base resistance properties of the samples were carried out as reported by Deepak and Sanjay (2012). The values were determined using Equations 1 to 3 respectively.

M_t (%) = $\frac{Wt-Wo}{Wo} \times 100$ ---------- (1)

A_t (%) = $\frac{Wt-Wo}{Wo} \times 100$ ---------- (2)

B_t (%) = $\frac{Wt-Wo}{Wo} \times 100$ ---------- (3)

Where Wt = weight of sample after absorption; Wo = original weight of sample.

C. Tensile Properties Test

Known weights were placed in the weighing pan at the same sequence for each sample and the elongation was measured with a metre rule at different times. The tensile strength, percentage (%) elongation and young modulus of each sample were calculated using Equations 5, 6 and 8 respectively.

Tensile strength (kPa) = $\frac{9.81 \times Mi}{Breadth \times Width} = \frac{Force}{Area}$ ---------- (5)

Where M_i = known weights utilised

% elongation = $\frac{L - Lo}{Lo} \times 100$ ---------- (6)

Where; L = new length of sample; Lo = original length of sample

Young modulus (Y_i) = $\frac{9.81 \times Mi \times Lo}{Breadth \times width \times (L-Lo)} = \frac{Stress}{Strain}$ --- (7)

Thus, the young modulus (Y) for each sample was calculated by taking the average of Y_i using Equation 8.

Young modulus (Y) = $\frac{\sum Yi}{N}$ ---------- (8)

Where N= number of Y_i summed.

D. Density and Specific Gravity

The densities of the samples were determined using the Archimede's principle approach. Thus, the densities and specific gravities of the samples were calculated using Equations 9 and 10 respectively.

Density (Di) = $\frac{1}{2}[\frac{M1i}{V1i} + \frac{M2i}{V2i}]$ ---------- (9)

Where; M1 and M2 = the different known mass of sample used; V1 and V2 = the displaced volume of M1 and M2 respectively; i = sample considered.

Specific gravity = $\frac{Density\ (Di)}{Density\ of\ water}$ ---------- (10)

E. Thermal conductivity test

This test was carried out by placing a known mass of each sample on a flat-bottom flask which contains constantly boiling water. All faces of the samples were insulated except for the face on the flask and a little opening was made on the adjacent top face. After 5 mins, the temperature of the face of the samples on the flask and that of the adjacent top face was quickly measured and recorded. Thus, the thermal conductivities of the samples were calculated from Equation 11.

k_i = $\frac{m \times Cpi \times dx}{A \times t}$ ---------- (11)

Where; k_i = conductivities of the samples
m = average (AVG) of the masses of samples used
Cp_i = specific heat capacities of the samples
dx = AVG of the thickness of the samples
A = AVG of the exposed areas of the samples
t = time for the heating process = 300 seconds
i = samples

F. Biodegradation studies

The biodegradability properties of the samples were carried out as reported by [3 and 4] with slight modifications. The samples were buried in different containers (aerobic condition and a depth = 6.5 cm) containing soil samples. The response of each samples to microbial attack were observed at regular time interval of 7 days by careful excavation and analysis of the physical condition of the samples in terms of size, texture, micro-organism deposition, etc. At the maximum time set for the studies, the samples were excavated and weighed. Thus, the % reduction in weight and the rate of biodegradation of each sample were calculated using Equations 12 and 13.

% reduction in weight = $\frac{Wo-wt}{Wo} \times 100$ ---------- (12)

Rate of biodegradation = $\frac{Wo-Wt}{Maximum\ time\ of\ degradation}$ -(13)

Where; Wo = original weight of samples; Wt = weight of samples after the degradation time

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III. RESULTS AND DISCUSSIONS

The results of the analysis are discussed as follows:

A. Water Absorption Resistance

It was observed that sample F (with the highest percentage of PVA, 80%) has the maximum resistance to moisture absorption as shown in Figure 1 and its curve is close to being a straight line which depicts that it was relatively more stable than the other samples [10]. Its maximum % increase in weight was 14.74 after 54 hrs and this value was kept constant till the test was completed. Sample A on the other hand with the least composition of PVA (15%) had the least resistance to moisture absorption. Its highest peak value was 62.96 after 6 hrs which thereafter decreased till the sample was totally disintegrated at the 54th hour.

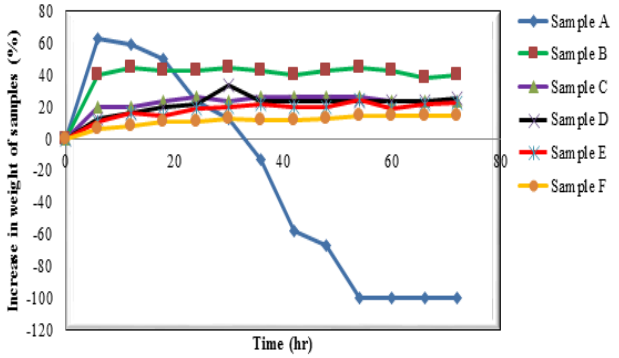

Fig. 1: Effect of PVA on Water Resistance of the Plastic Samples for 72 hours

Also, Figure 2 shows the maximum percentage increase in the weight of samples at the corresponding reference time. In view of this result, the sample with the low percentage increase in weight at a relatively high reference time possesses the highest stability and resistance in the water medium. Based on this, sample F (with the highest PVA composition) was still the highest. The increase in the composition of PVA in the blends therefore, led to increase in the resistivity of the samples to moisture absorption thereby augmenting for the weak resistance nature of pure thermoplastic starch [8].

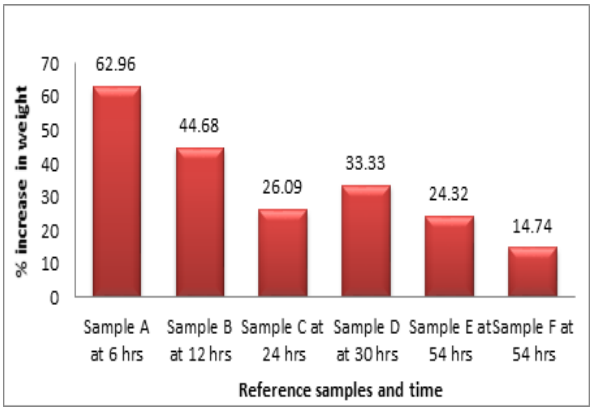

Fig. 2: Percentage Increase in Weight of Samples for Water at 25^{o}C

B. Resistance to Acid and Base

The sample with the lowest percentage increase in weight at a relatively high reference time possesses the highest stability and resistance in the acid medium. sample F (with the highest PVA composition) still gets the credit. It was noted that after 42 hrs, all the samples completely disintegrated which depicts that PVA complements the weakness, instability and low resistance of pure TPS in acidic medium. In case of resistance to base, it was obvious that sample F (with the highest composition of PVA) was relatively more stable and approaches a constant absorption value faster as shown in Figure 3, than the other samples within the period of test.

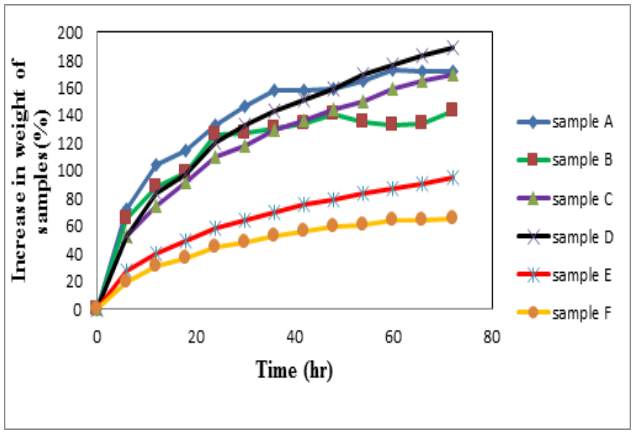

Fig. 3: Effect of PVA on Base Resistance of the Plastic Samples for 72 hours

C. Mechanical Property Tests

With respect to the results obtained from the tensile test on the samples, it was established that the tensile strength of the samples at increasing composition of PVA increased. This fact depicts that as increases were made to the composition of PVA in the samples; higher values of load (force) were required to rupture/break the samples but this trend was altered for sample D (with equal mass of PVA and TPS); and this shows that a favourable property (in strength) is achieved with equal mass ratio of PVA and TPS. Thus, the tensile strength of samples A, B, C, D, E and F were 0, 0, 83.75, 340.81, 164.23 and 384.47 kPa respectively.

It was also observed that increase in the PVA composition in the samples, resulted into increase in percentage elongation with increasing load [11]. Sample F with the highest % PVA had the highest % elongation while samples A and B had the least (Figure 4). However, sample D (with equal mass of PVA and TPS) showed a favourable property (in strength) was achieved with equal mass ratio of PVA and TPS.

The Young Modulus of sample F was the least value with respect to the results obtained via the analyses of the samples. This trend of decrease in young modulus as the amounts of PVA were increased in the samples was altered for sample D (with equal mass ratio of PVA and TPS) depicting that a favourable property (in elasticity) is achieved at same mass composition of PVA and TPS. Thus, as increase was made to the composition of PVA in the samples, they attained high level of elasticity and flexibility;

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and the young modulus of the samples A, B, C, D, E and F as obtained from the test were ∞, ∞, 1122.52, 459.12 1537.20 and 310.10 kPa respectively. The results from the density and specific gravity tests established that PVA/TPS blend are highly compatible due to the fact that all the blends have approximately the same density and specific gravity. This illustrates that a unit change in the composition of PVA in the blends (that is, weight) gave rise to a proportional unit change in the volume of the blends [12].

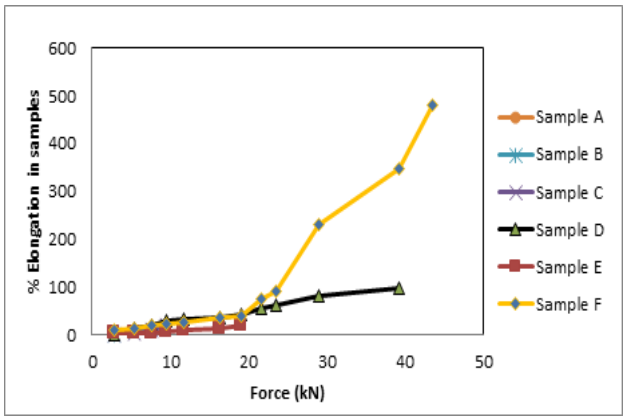

Fig. 4: Percentage Elongation of Samples at Increasing Load

Thus, the density and specific gravity of the whole samples was 1.2 g/cm^3 and 1.2 respectively. With respect to the thermal conductivity test, it was established that increase in the composition of PVA in the blends, led to increase in thermal conductivities of the samples. The thermal conductivities (k) of the samples A, B, C, D, E and F were 1.68×10^{-3}, 1.80×10^{-3}, 1.92×10^{-3}, 1.96×10^{-3}, 2.08×10^{-3} and 2.20×10^{-3} W/m.K respectively.

D. Biodegradability

With respect to the observations seen on the samples, the increase in the composition of PVA in the blends decreases the rate of degradation; but the blend is generally biodegradable. This assertion is made due to the facts that as the samples were excavated and physically observed at intervals of 7 days [5];

- Samples (A and B) with relatively lower amount of PVA were already disintegrating while no disintegration was observed for the other samples (C, D, E and F).
- Although there was no disintegration in samples C, D, E and F, but an increasing amount of physical evidences of microbial attack on the samples was observed as the burial time increased.
- Also, cracks (sample C) and less rigidity (sample D, E, and F) were also observed as the burial time increased. Thus, at each point of observation, the strength of samples in the order of increasing PVA composition decreased.

Based on these findings, it is obvious that PVA/TPS blend is biodegradable. In addition, Plate I showed the physical state of the samples before and after 23 days of burial.

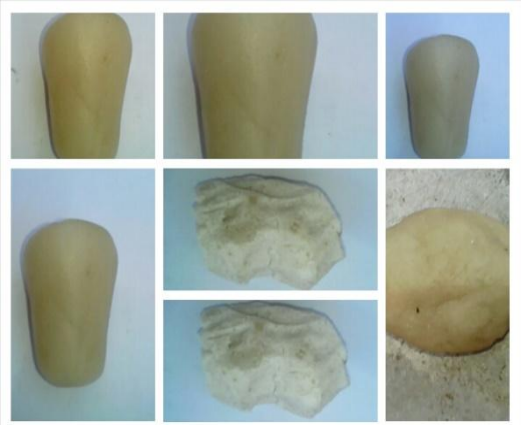

Plate 2: Physical Appearance of Plastic Samples Before 23 days of Burial

Plate 2: Physical Appearance of Plastic Samples After 23 days of Burial

IV. Conclusion

Biodegradable plastics have been successfully produced from sweet potatoes using the aforementioned approach and experimental procedures. The plastic samples produced were characterized in order to determine their physical, mechanical properties and biodegradability. Based on the results obtained, it could be concluded that the feedstock, sweet potatoes, which are available in large quantity in Nigeria is a good source of starch for the production of biodegradable plastics. Their renewability, and minimization of environmental pollution/hazards are great achievement.

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