

Explicit Microstructural and Properties of Polyvinyl Alcohol /Eggshell Particles as Biodegradable Composites for Packaging Industries

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Abstract

The new insights in the development of biodegradable composites for packaging industries, using PVA (polyvinyl alcohol) and eggshell ash particles (ESAp) were investigated. The composites were produced using the modified solution cast method. In the experimentation; 0, 5, 10, 15, and 20wt% ESAp were used in the production of the composites. Tensile, Impact energy, Water absorption, Density, and Biodegradability tests were carried out on the resulting composites samples to determine their characteristics and composition with the most suitable property for mechanical and packaging applications. The composite samples showed variants in mechanical properties according to the results obtained from the tests carried out. This led to the conclusion that for optimum mechanical properties for packaging applications, bio-composites with the studied composition should be obtained at 15wt%ESAp. It was established that the developed composites film can be used in the packaging industries.

Keywords

Eggshell particles, polyvinyl alcohol, biodegradable composites and properties

1. Introduction

In modern societies, petroleum-based synthetic polymers are being widely used for a variety of applications, such as; polyolefin in packaging, bottle, and molding products (Abdullah et al. 2017). Globally, the annual disposal of petrochemical plastics is capped at nearly 150 million tons, which amounts to dangerous environmental problems during disposal due to its non-biodegradability, especially with the continuous increase in production and consumption of these materials. Moreover, these plastic wastes are capable of resisting microbial attack. This causes undesired pollutants in the soil, rivers, and marine environment (Bahrami and Fattahi, 2021).

Nowadays eco-friendly biodegradable polymers receive great attention as the next best alternative to partly or completely replace the consumption of petroleum-based plastic materials. These biodegradable polymer materials can completely degrade into natural ecosystems such as active sludge, natural soil, lake, and marine without any part left as pollutants in the environment (Lal et al. 2020). On the other hand, these eco-friendly polymers are quite capable of chemical transformation through the action of biological enzymes, microbes, and microorganisms that act on these polymers and break them into non-harmful chemicals, which dissolve into the environment. Several researchers have reported that the biodegradability property of the bio-composites has been the most important factor for many composites (Yurong and Dapeng, 2020).

Biodegradable composites are used in producing packaging materials for the food packaging industries. The use of highly improved packaging materials that can reduce the decline in quality of the food and also have a less toxic impact on the environment has always been at the forefront of packaging industries[5]. The constant increase in population, resulting in an increasing demand for fresh foods, and quality products have facilitated the increased efforts being made by researchers to meet the ever-increasing demands for safe food packaging methods. Food packaging helps to increase the shelf-life of the products and to also change the sensory properties of the packaging

material without harming or contaminating the packed food in any way (Seligra et al., 2016; Andayani et al., 2015). Rice husk, wood, corn husk has been successfully used in the production of packaging polymer film (Park et al., 2005). However, this present work will report for the first time the suitability of using the very abundant eggshell waste in the production of polymer composite film for packaging applications.

2. Materials and Method

The brown eggshells were chosen in this work because a report on higher CaCO_3 evident in brown eggshells than their white eggshells counterpart is already documented (Hincke et al., 2012). The eggshell was collected from the University of Nigeria Nsukka farm. The raw brown eggshells were cleaned to remove the membranes by washing and drying for 24 hours. The cleaned eggshells were then calcined in a muffle furnace at a temperature of 700°C for 3 hours. The pulverization of the calcined ES_p was done using a ball milling machine of 36 stainless steel balls at a speed of 250rpm. The particle size analysis of the pulverized ES_p was executed using a set of sieves, which permitted sieving to a particle size of $65\ \mu\text{m}$. The composites were produced by dissolving the Polyvinyl Alcohol (PVA) with water and adding sizes of 0, 5, 10, 15, and 20 wt%ES_p and stirring vigorously for 10 minutes at a temperature of 95°C . After gelatinization, the solution was then cast over ceiling plywood used as a mold and left to dry at room temperature for 24 hours. The film was then further dried in an electric oven for about 2 hours at 70°C . Figure 1 display the production process. The water absorption was done by immersing the samples in distilled water at room temperature (25°C) for 24 hours, after which their surface was wiped by cleaning the moisture, and their weights measured. The water absorption of the plastic films was calculated using equation (1).

$$W_a (\%) = [(W_e - W_o)/W_o] \times 100 \quad (1)$$

Where:

W_e = the weight of plastic film at the adsorbing equilibrium

W_o = the first dry weight of the plastic film

The density of the samples were obtained by weighting the sample in the air using an electronic weighing balance and recording (Figure 1). Thereafter, the densities are calculated by dividing the mass of each composite specimen with the corresponding volume. The biodegradable tests were done by burying the sample in soil for 30 days. The buried specimens were then removed from the soil and all dirt wiped off. The initial weights of the buried samples were previously recorded before the test. Upon test completion, the weight changes were calculated after taking their post-test weights. The extent of wearing away of the samples was determined by observing the changes in dimension, physical appearance, and weight changes as well. The tensile test was carried out as per the ASTM D5045 standard. A testometric universal testing machine was used. The impact strength was determined using the Charpy impact strength machine. A Rectangular sample of $80 \times 10 \times 4\ \text{mm}^3$ with a V-notch (2mm-depth) was used. The microstructure of the samples was determined using a scanning electron microscope (SEM) model: VEGA 3 TESCAN.



Figure 1. Photograph of the production process

3. Results and Discussion

Figure 2 show the density and water absorption of the developed polymer composites film. It was observed that the density of the composites reduced as the w%ESp increased from 0 to 20wt%. The decrease in density was attributed to the lower value of ES_p than PVA, while the water absorption of the composites reduced to the optimal value of 15wt% with 16.85% enhancement in the water absorption. The decrease in water absorption was because the ES_p was able to fill the void space in the PVA. The level of water absorption obtained in this work is within the recommended standard for packaging application.

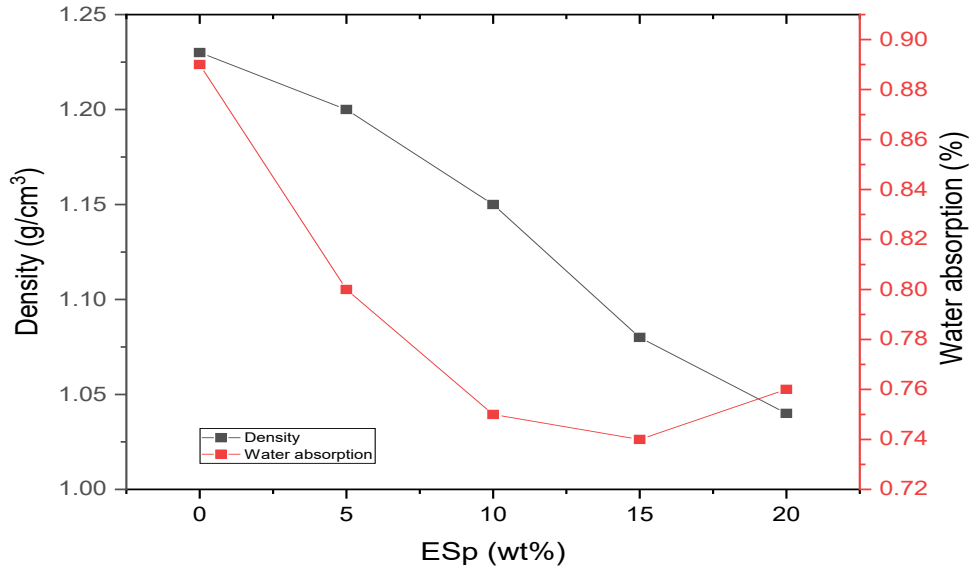


Figure 2. Variation of Density and water absorption with wt%ESp

Figure 3 present results of the tensile strength and the tensile modulus. It can be seen that the strength increased up to 15wt%ESp addition to the PVA. The increment in tensile strength was attributed to the fact that the ESsp supports the stress transfer to the matrix. Also, the incorporation of ESsp to the PVA matrix resulted in a decrease in the elasticity of the film and results in the hardening and strengthening of the film. The young's modulus values increase with increasing filler content due to the stiffening effect of the ESsp. A 51.2% increment in tensile strength was achieved in this work.

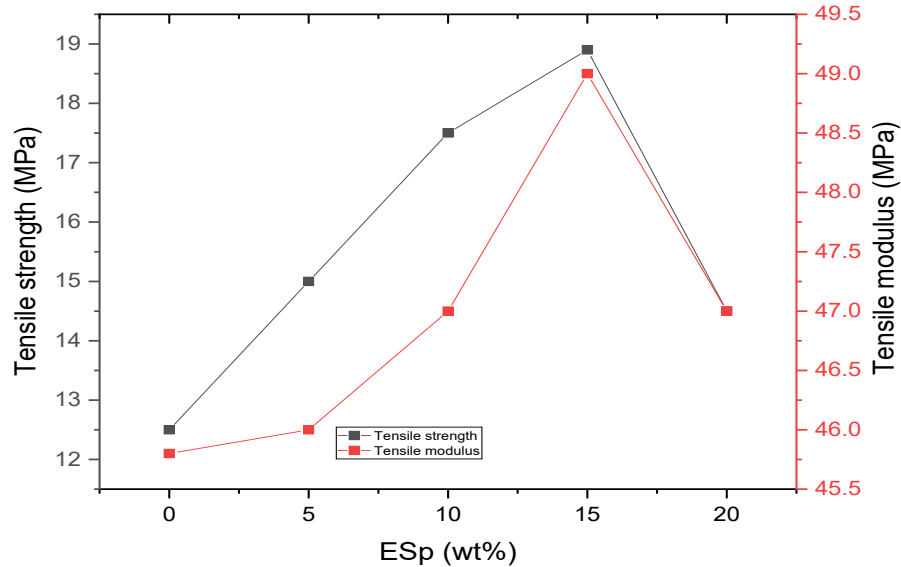


Figure 3. Variation of Tensile strength and tensile modulus with wt%ESp

Figure 4 shows the impact energy and biodegradable results of the composites. It is quite obvious that the impact energy increases up to 15wt%. This is mainly attributed to the reduction of the elasticity of the material due to ESp addition thereby reducing matrix deformability. An increase in ESp concentration reduces the ability of the polymer matrix to absorb energy and thereby reducing the toughness at 20wt%. It can be seen that the weight loss of the bio-composites demonstrated an increasing trend as higher filler content ESp was added. A 158.33% biodegradation was obtained in this work. Microbial degradation generally results from the action of naturally occurring microorganisms and microbes such as bacteria, fungi, algae, and others. These microorganisms attack the filler much faster than the matrix.

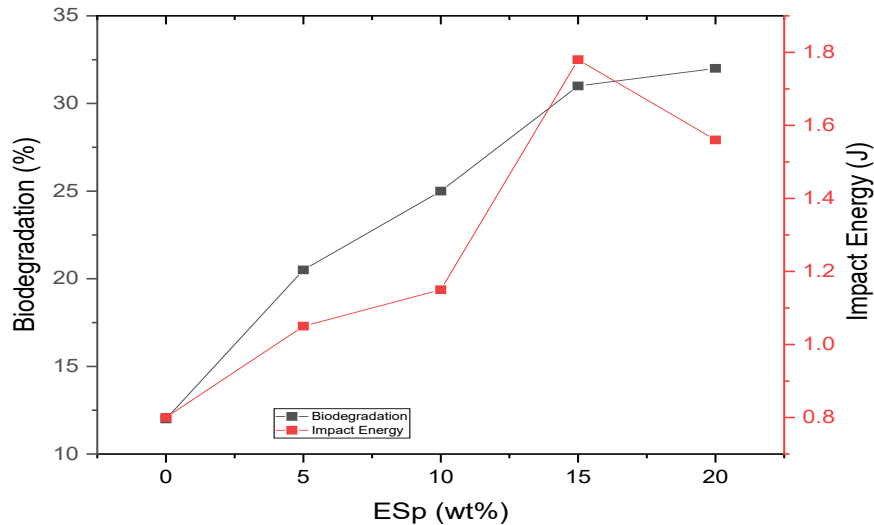


Figure 4. Variation of biodegradation and impact energy with wt%ESp

Figure 5 shows SEM micrograph of the composites. It can be observed that there were uniform distributions of the ESp(white phase) in the PVA at 15wt%ESp. However, there was a slight agglomeration with 20wt%ESp. The good interfacial adhesion between ESp and matrix in the composite was the major reason for the enhanced properties achieved at 15wt%ESp.

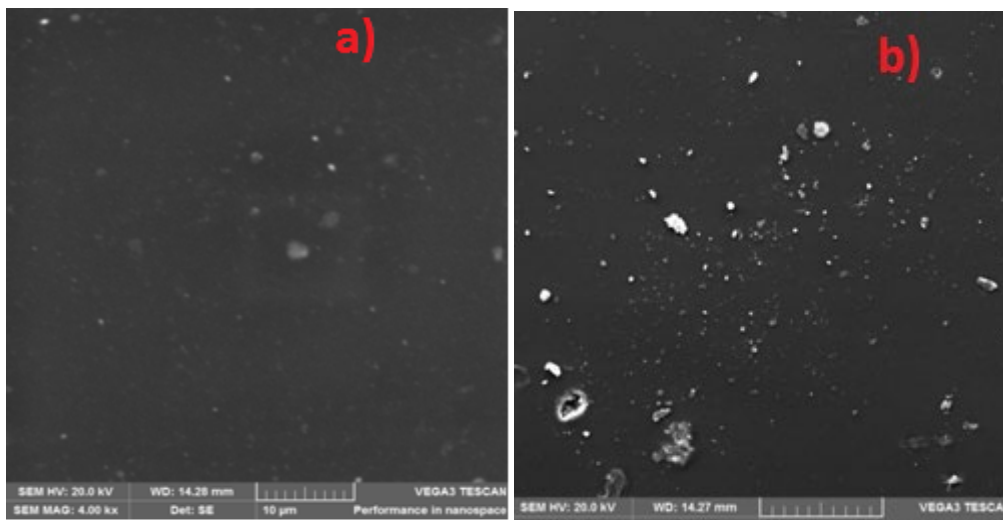


Figure 5. SEM micrographs of a) PVA/15wt%ESp b) PVA/20wt%ESp

4. Conclusion

The development of the eco-friendly synthesis of films of PVA/waste eggshell (ESp) in water using glycerol as a plasticizer was presented in this work. In the course of the work, the following conclusions were made: A 158.33% degraded in soil within 30 days, 51.2% improvement in tensile strength, and 16.85% reduction in the water absorption were obtained at 15wt%ESp addition to PVA. The results of the biodegradation and mechanical properties show that the blend films might be used in sustainable packaging. It was established that waste eggshells can be used in the production of polymer films for the packaging industry.

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Biographies

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