Engineering, Environment

Development of organic material based composites for packaging application using recycled papers

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Abstract

This study shows the effects of cassava starch as binder on the flexural strength and the water absorptivity properties of cassava starch bonded paper pulp based composites. Paper pulp was produced by chopping waste papers into smaller pieces and soaked in water for 2 weeks after which it was pulverized in the grinding machine to form paper pulp. The starch slurry was prepared with boiled water and stirred properly to produce lumps free starch slurry. The starch slurry after cooling was preserved in a container. The composites were developed by forming the homogeneous pastes from the mixture of starch with white and brown papers slurry, respectively in predetermined proportions. The developed composites were allowed to cure at room temperature in the laboratory for 28 days after which flexural and water absorptivity tests were carried out on the samples. It was deduced from the work that both white and brown paper pulp based composites possessed improved properties than the control sample which was without starch. However, starch bonded brown paper pulp based composites gave the best bending properties while starch bonded white paper pulp based composites gave the best water absorption resistance response.

Keywords

Waste paper; Organic; Cassava starch; Paper pulp; Recycled; Composites; Flexural properties; Water absorption

Introduction

With regards to the continuous desire for structural and engineering materials that have combinations of excellent properties combined with the increase in awareness levels about the environment, the interest to develop biodegradable material via renewable sources seems to be growing. This is where composite materials get their advantages. In many cases, pure materials do not have these desired excellent properties, hence, the reasons why material engineers developed composite materials that are made up of different constituents such as the matrix and the reinforcement. Composite materials generally have properties such as lighter weights, ability to be tailored for optimum strength and stiffness, improved fatigue life, corrosion resistance, and reduced assembly or manufacturing costs due to fewer detail in parts and fasteners [1].

Properties of composite are strongly dependent on the properties of their constituent materials, their distributions, and the interaction among them [2]. The composite properties may be the volume fraction sum of the properties of the constituents or the constituents may interact in a synergistic way resulting in improved or better properties. Apart from the nature of the constituent materials, the geometry of the reinforcement (shape, size and size distribution) influences the properties of the composite to a great extent. The concentration, distribution, and orientation of the reinforcement in the matrix also affect the properties of the composite. The interface has characteristics that are not depicted by any of the component in isolation. The interface is a bounding surface or zone where a discontinuity occurs, whether physical, mechanical, chemical etc. To obtain desirable properties in a composite, the applied load should be effectively transferred from the matrix to the reinforcement via the interface [3]. This means that the interface must be large and exhibit strong adhesion between reinforcement and matrix. Failure at the interface (called de-bonding) may or may not be desirable.

Globally, recycling of waste materials is an interesting issue to the scientists and engineers and this was one of the reasons for using them as a major source of material for the development of low cost packaging materials in this research [4-5]. In the United States, paper constitutes the most important material for packaging and containers largely because of its low cost and wide availability. It is also perceived as a sustainable material because it is derived from plants and is recycled at a very high percentage (62 %). Waste papers have been observed to be available in homes, schools and offices where papers are highly used. In Nigeria as well as many developing countries, waste papers are usually burnt or discarded haphazardly. This implies that, the potentials in these waste materials are presently under-utilized [6].

Starch binders which are majorly produce from cassava in Nigeria, possess good ductility, good bind-ability, self-curing properties and hygroscopicity-resistance in their incorporated composites. Starch can be modified by physical or chemical methods to improve its structure and binding property as applicable to foundry as a main binder. Development of α-starch based composite binders by [7-8] in earlier stage can be regarded as a main starch binder for foundry. The thermoplastic properties of starch have been extensively studied [9] while many technologies have been used to process starch, the easiest way of obtaining a film is by casting from a solution. To obtain useful materials from starch, the native properties must be enhanced because of starch's high water sensitivity. The influence of water content and of external plasticizers like glycerol and sorbitol has been investigated to decrease the brittleness of these materials [10]. Since starch is attributed to offer a favourable combination of cost, availability and performance, it is said to be very effective and valuable as compared to other polymers [2]. Furthermore, cassava starch has been noticed to possess good properties that will enhance the engineering properties of composites. This has generally been focused on renewable and sustainable reinforced composites.

The aim of this research is to investigate the effect of cassava starch as binder on the flexural and water absorption properties of cassava starch reinforced paper pulp based composites. The selection of these basic materials take into cognizance environment factors and the reason for using organic materials in which waste paper is a major material. The outcome of the research has shown the possibility of using these materials for the development of environmentally beneficial composites that are light and strong for packaging industries.

Material and method

In this research, the following materials and equipment were used for the production of the paper based composites; Waste office papers (white) and newsprint papers (brown) were the major source of materials used. Others are cassava starch and water.

Preparation of particulate paper and starch slurry

The papers to be pulverized were soaked in water for 2 weeks so as to ease the pulverizing process after which they were poured inside the grinding machine and grinded to form the paper pulp. The pulverized paper was squeezed and sun dried for 5 days to obtain particulate material.

The starch solution was prepared by mixing 4 kg of cassava starch with 300 cm^3 of water at room temperature in a vessel. The solution was mixed with hot water and stirred properly to produce lumps free starch slurry. The starch slurry was allowed to cool in air for about 15 minutes before being used.

Composites development

Composites were developed by forming the homogeneous pastes from the mixture of starch and white as well as brown paper slurries, respectively in predetermined proportions as shown in Table 1.

Table 1. Mixing proportions of Starch with white and brown papers

Samples	Paper in slurry (%)	Starch as the binder (%)
Control	100	-
A	95	5
B	90	10
C	85	15
D	80	20
E	75	25
F	70	30
G	65	35
H	60	40

The paper slurries were formed by blending 1 kg of the sun dried particulate papers with 2 litres of water followed by a thorough mixing in a container to form white and brown paper slurries.

Each representative sample were produced in triplicate by pouring the homogenous paste into the flexural moulds. Compression moulding machine was used to press the samples inside the mould at room temperature with a load of 20 KN for 5 minutes. The samples were removed from the mould after compaction and allow drying at room temperature in the laboratory for 28 days.

Flexural test

Flexural test was carried out in accordance to (ASTM D790, 2002) standard test method for flexural properties of polymer matrix composite materials. The flexural test was carried out by using a universal testing machine that works on a three-point flexural technique. The test speed was 50.00 mm/min over a span of 100.00 mm. Three samples were tested for each representative sample from where the average values for the test samples were used as the illustrative values.

Water absorption test

Water absorption test was carried out in accordance with ISO 175. In determining the water absorption property of the composite, each of the composite were weighed in air when dried using an electronic weighing balance; FA2104A Model which is of high precision ± 0.0001 g accuracy before immersion in 700 cm^3 distilled water medium. This test was done for the various samples of the composite in 6 hours. The composite samples were removed, cleaned and readings were taken every hour for 6 hours. The weight after a period of 6 hours was taken and the data collected was used to determine the % water absorption using equation (1).

$$\%\ Water\ Absorption = \frac{Final\ Weight - Initial\ Weight}{Initial\ Weight} \times 100 \quad (1)$$

The flowchart for the process used in this research was as shown in Figure 1.

The process starts with paper and starch slurry preparation followed by blending of these constituents to develop the composites using open mould techniques before carrying out the flexural and water absorption tests on the cured samples.

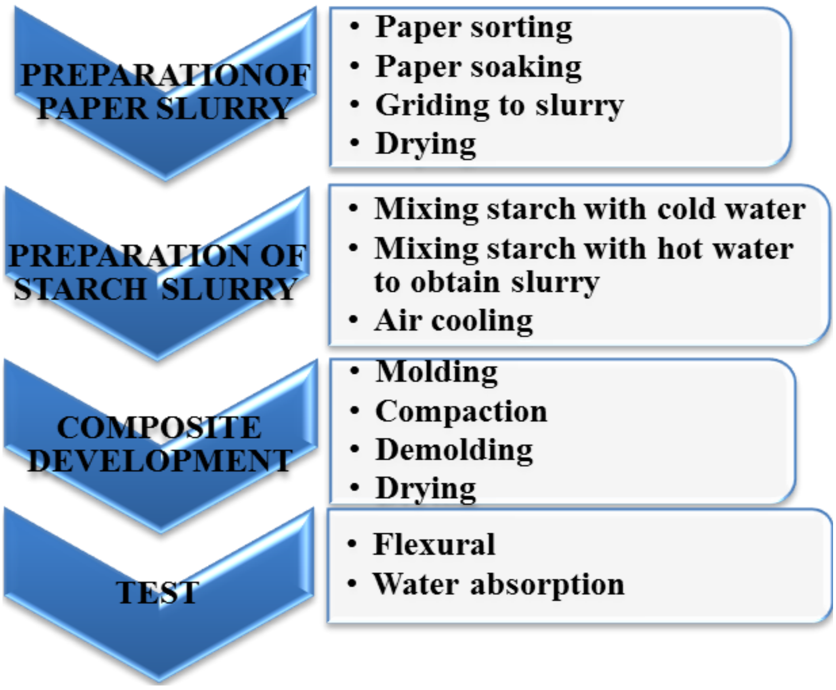

Figure 1. Flowchart of the production process

Results and Discussion

Figure 2 show the responses of the deflection at peak. It was observed from the plots that all the samples possess comparatively good deflection responses before failure with respect to control except for the sample with 5 wt % starch.

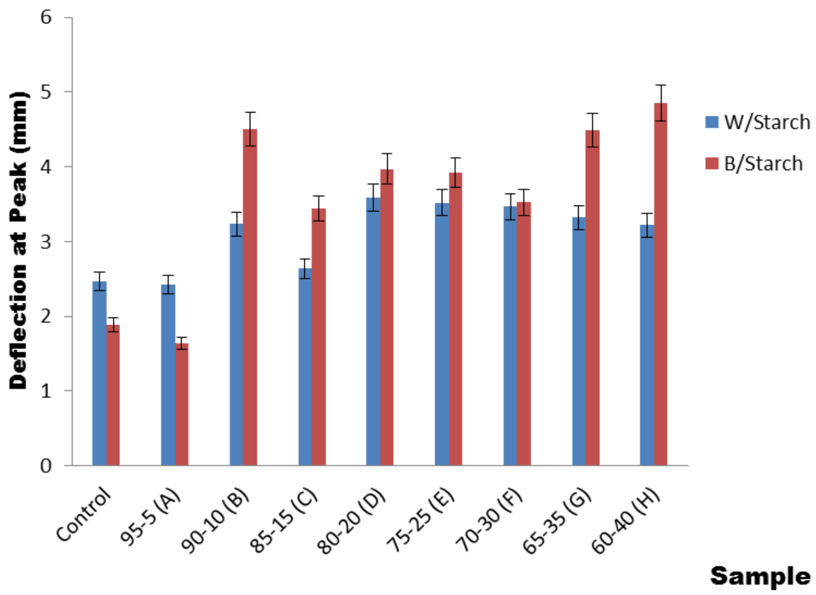

Figure 2. Plots of variation of deflection at peak with samples

This implies that addition of 10-40 wt % of starch can aid good deflection property. Cassava starch bonded brown paper pulp with 60 wt % brown paper pulp and 40 wt % starch possess the highest value of 4.85 mm followed by cassava starch bonded brown paper pulp with 90 wt % brown paper pulp and 10 wt % starch having a value of 4.49 mm and cassava starch bonded brown paper pulp with 65 wt % brown paper pulp of value 4.48 mm was next. Brown paper pulp based composites were better enhanced in this property compared to white paper pulp based composites. Comparing these with the control samples that have values of 2.47 and 1.89 mm for white and brown paper pulp, respectively, it was observed that the property has been improved by about 157 % for the brown paper that possess the best property.

It was revealed that the property tends to increase as the starch content increases for brown paper based composites while it tends to decrease as the starch content increases for white paper based composites. This is an indication that the constituents of the two papers differ and that affects the reactions taking place between the paper pulp and the starch. The presence of lignin in brown paper pulp which is a waxy polymeric material may contribute to the enhancement in the ductility of brown paper pulp while the removal of lignin from the paper pulp through bleaching, the process for the production of white paper, may be responsible for the weak or low ductility obtained from the white paper pulp based composites.

The results of the variation of bending strength at peak were as shown in Figure 3.

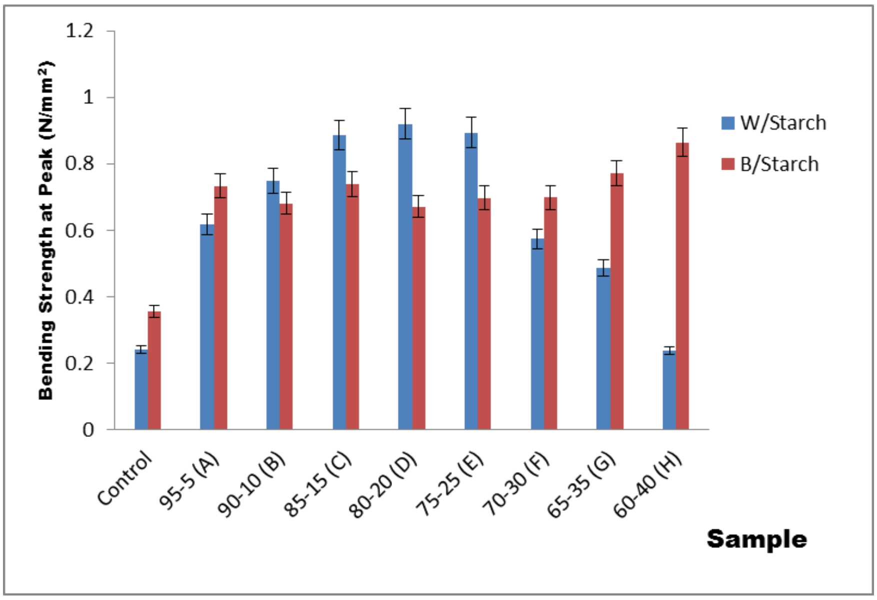

Figure 3. Plots of variation of bending strength at peak with samples

Of the results obtained in the figure 3, it was observed that, the use of cassava starch as binder for these paper pulps increases the bending strength of the developed composites more than the bonded paper without cassava starch which serves as the control. Also, noticed was that, the strength of the developed composites tends to increase as the binder content increases, particularly in the cassava starch bonded white paper pulp composites from 5-20 wt% addition of starch followed by a decrease till 40 wt %. The results revealed that white paper pulp bonded with cassava starch gave the best output compared to brown paper pulp cassava starch bonded. The best result was obtained when 80 wt % of the white paper pulp was blended with 20 wt % of cassava starch with a bending strength value of 0.92 N/mm^2 followed by 75 wt % white paper pulp blended with 25 wt % cassava starch composite with a value of 0.89 N/mm^2 and 85 wt % white paper pulp blended with 15 wt % cassava starch with a value of 0.88 N/mm^2, respectively. Comparing these with the ordinarily bonded white and brown paper pulps strength with values of 0.24 and 0.36 N/mm^2, these has culminated to greater enhancement from both paper pulps, respectively. The addition of starch within 15-25 wt % gave the optimum enhancement in the bending strength at peak for the white paper pulp based composites. The improvement in the enhancement of the bending strength at peak for white paper pulp over brown ones was due to the presence of lignin in the brown paper and the delignification that was achieved in white paper during bleaching. The presence of lignin in brown paper pulp prevents proper blending between the paper and cassava starch binder during mixing, hence, bleaching paper [11-12] aid proper blending of binders with the white paper pulp. This was made possible because the binders will penetrate easily into the paper thereby enhancing interfacial bonding strength and consequently, the strength of the developed composites.

Figure 4 illustrates the response of the materials to bending modulus. The results revealed that the bending moduli were improved in all the starch bonded paper pulp based composites for both white and brown. However, no definite order was noticed in the enhancement but best results were obtained from low weight fraction of between 5-15 wt % cassava starch additions. Bending modulus was observed to be high due to increase in paper pulp content while at higher weight fraction of between 20-40 wt % cassava starch contents, bending modulus was observed to be low following the decrease in the paper pulp content. It follows that the strength and stiffness of the developed composites were enhanced rapidly by cassava starch content within the low weight fraction range. From the results, it was also observed that, the modulus was better enhanced in cassava starch bonded brown paper pulp with 95 wt % brown paper pulp, followed by 85 wt % white paper pulp and 75 wt % white paper pulp which has values of 47.74, 47.62 and 41.81 N/mm^2, respectively.

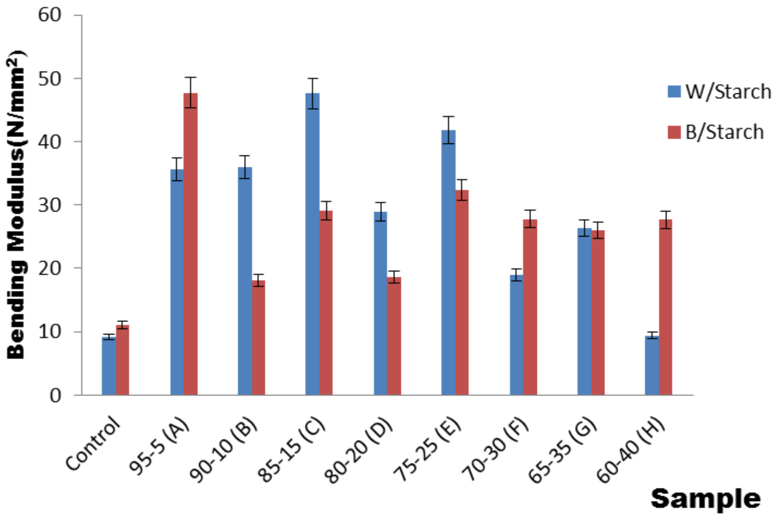

Figure 4. Plots of variation of bending modulus with samples

This result support the reason why deflection at peak was better enhanced at higher weight content of cassava starch in Figure 2 since the starch was mostly responsible for the ductility characteristics of the composites. The corroboration was further observed from the fact that, the samples with least deflection at peaks were the ones with the highest bending modulus.

Figure 5 represent the results of the bending strength at yield.

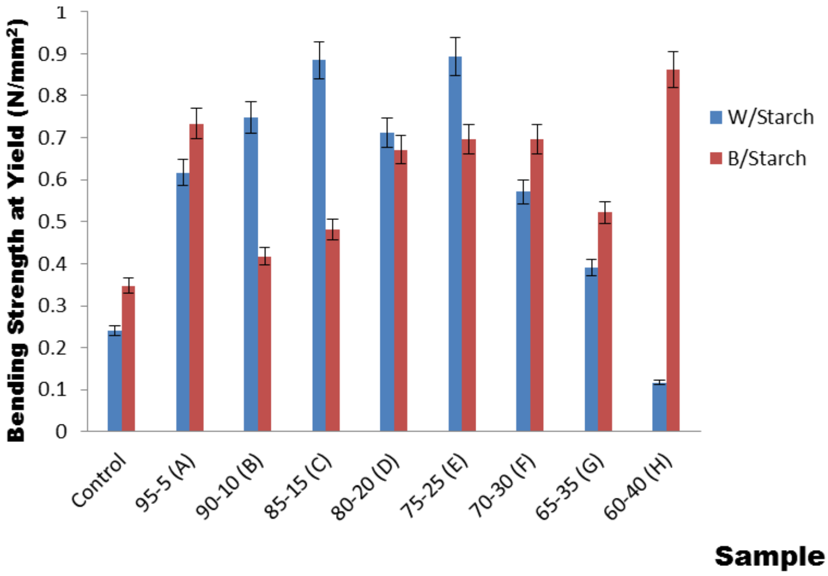

Figure 5. Plots of variation of bending strength at yield with samples

The plots revealed almost similar pattern to that of bending strength at peak. Best results were obtained from 75 and 85 wt % white paper pulp bonded with cassava starch of 25 and 15 wt % with values 0.89 and 0.88 N/mm^2, respectively. The result agreed with what was obtained from the use of natural rubber as binder in recycled waste paper pulp bonded composites [6]. This was followed by 40 wt % cassava starch bonded brown paper pulp with a value of 0.86 N/mm^2. The obtained results were due to the same reasons for the observed bending strength at peak.

Figure 6 shows the plots of the variation of water absorption properties with time for each of the sample for 6 hours.

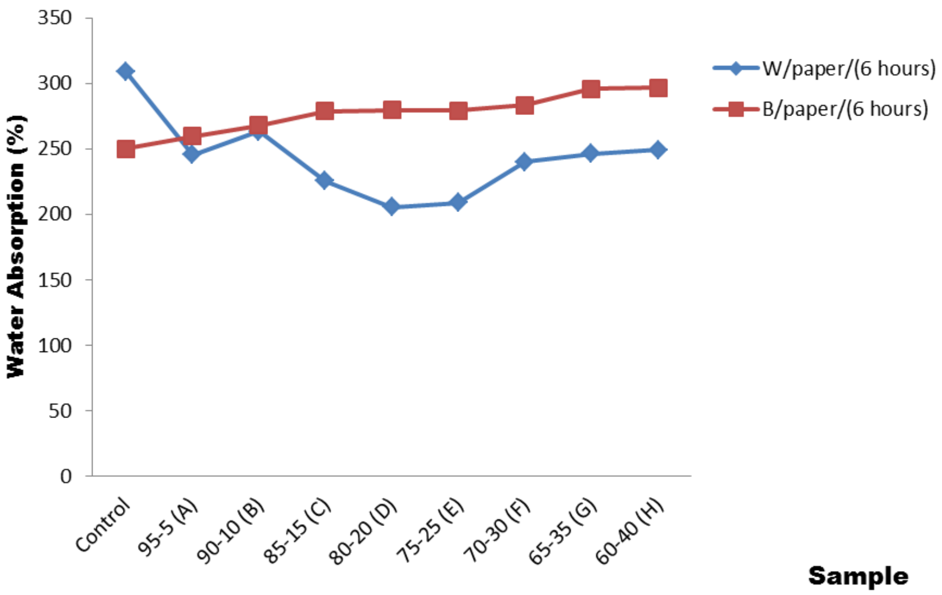

Figure 6. Plots of variation of water absorption with samples

The results revealed that white and brown paper based composite samples followed a different trend. It was noticed that as the paper content decreases, the rate of water absorption decreases in white paper pulp based composites while the absorption tendency increases as the brown paper pulp increases for brown paper pulp based composites. This is as a result of increase in the interfacial bonding strength at the interface of the white paper pulp based composites and the cassava starch. This culminated to a decrease in the rate of diffusion of water molecule into the samples as the addition of cassava starch binder tends to decrease the pores present in the material. However, brown paper pulp reinforced samples absorbed much water than the white paper pulp samples. This may be due to the presence of lignin which tends to absorb much water in the brown paper. From the results, cassava starch bonded white paper pulps within 15-25 wt % gave the best response with optimum result emanating from 80 and 75 wt % white paper pulps with values 205.65 and 208.89 %, respectively. This was followed by cassava starch bonded white paper pulp with 85 wt % white paper pulp content having a value of 225.3 %. This result further substantiates the superiority of cassava starch bonded white paper pulp composites within 15-25 wt % as obtained in bending strength and modulus properties. The superb water resistance capability of the samples in addition to the excellent bending strength at peak and at yield properties as well as modulus of the materials have placed them above others**.**

Conclusions

The results revealed that the developed composites were of good properties compared to the control sample which was without starch. Brown paper pulp gave the best bending properties while white paper pulp gave the best performance in terms of water absorption properties.

The optimum mixing proportions for white paper pulp/starch bonded composites was within the range of 15-25 wt % cassava starch additions having aided the best responses in terms of bending and water absorption properties while different weight fractions within the ranges considered gave the best responses for the properties with respect to brown paper pulp based composites.

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