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Waste sawdust incorporated starch/fiber composite for packaging materials

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Abstract

This work aims to develop a biodegradable composite material using maize starch with cellulose fiber from banana stems. Both are very cost-effective and commonly known materials. Cellulose fiber has been extracted from the banana stem using chemical methods. While extracting the banana stems underwent the alkaline treatment by immersing them into 2-3% NaOH solution at 80-90 ◦C for 2-4 hours. Powder of cellulose fiber has been used here. To get this powder the stems are bleached into H_2O_2 and low concentration of NaOH. After bleaching the cellulose fibers are cleaned and dried for 60◦C overnight. Then the fiber has been ground by mortar and pestle. For the preparation of the starch plasticizer mixture 5% maize starch, 90% water, 2.5% glycerol, and various percentage of cellulose fiber has been used (for each percentage, different samples have been made). This mixture has been heated continuously for 100◦C with magnetic stirring until gelatinized. After gelatinized for drying the samples were heated to 60◦C overnight. For the determination of various characteristics, the samples have been tested XRD and tensile strength as mechanical tests. These tests have given knowledge about its crystal structural, and mechanical properties. The results we have got here are outstanding. This bio-composite material can be a good alternative for packaging purposes and also can be used as a shopping bag. It is also environmentally friendly.

Keywords: Composite, Maize starch, Banana stem, biodegradable, packaging.

1. Introduction

There is significant interest in producing bio-based products and novel processing technologies to reduce our reliance on fossil fuels and petroleum-based products. Starch is one of the most promising renewable biopolymers due to its versatility, low cost, abundance, and biodegradable nature. Native starch can be transformed into thermoplastic starch by heating and shearing it in the presence of a plasticizer. Under these conditions, starch granules are restructured, plasticized, and melted, resulting in a material with properties similar to thermoplastics.[1], [2], [3]. As a result, starch has been employed to create biodegradable plastics, which are widely used in food packaging films, shopping bags, and flushable sanitary product backing materials [[4]]. However, in order to manufacture starch bio composites (SBs) with improved qualities, a few disadvantages of this material, such as its low mechanical properties, must be solved. These constraints can be solved utilizing many ways, such as introducing plasticizers, combining the starch with polymers, chemically modifying the starch, and adding fibers and nanoparticles as reinforcement[5], [6], [7].There are some researches about packaging material polylactic acid with chitosan matrix[8], fish gelatin with chitosan matrix[9], maize starch with chitosan addition to PVA[10], biowaste orange peel with chitosan/PVA[11]. But here banana stem fiber along with saw dust and maize starch has been used which is a completely new idea. The all materials are natural waste. By increasing saw dust, the tensile strength can be improved Various types of fibers are used as reinforcement agents to enhance their properties. According to a news report published on 12 June 2023 at Bangla Tribune Bangladesh is one of the top 20 banana-producing countries in the world, with production reaching 826,000 metric tons and a market value of $122 million in fiscal year 2020-21. The banana tree gives only one time in its life cycle. After getting fruits it becomes a waste material. So, it will be tremendous to use its stem fiber as a reinforcement agent. The fiber's primary components are cellulose (55-65%), hemicellulose (15-25%), lignin (10-15%), and pectin (3-5%). Cellulose, the primary element of banana fiber, lends structural integrity to the fiber. Lignin contributes significantly to plant mechanical strength. The yellowish tint of banana fiber is primarily owing to its lignin concentration. The chemical makeup of banana fiber varies based on the species, geographical location, agro-climatic conditions, soil nutrients, plant age, and extraction methods[12]. This banana stem fiber also produces cellulose nanocrystals (CNC). CNCS has arisen as a highly interesting reinforcement agent because of its unique properties like biodegradability, nontoxicity, high strength, low cost, etc. Wood powder is a commonly used natural fiber for thermoplastic reinforcement. The use of wood as a composite reinforcement has garnered increased interest in recent years, both from academia and industry, as an inexpensive filler to boost the

mechanical characteristics and thermal stabilities of thermoplastics or to minimize raw material prices. Because wood flour can be made from sawdust, pulp mill wood leftovers, bark, nutshells, or straw[13].

The main objective of the present study was to prepare a packaging material from maize starch with banana stemfiber. starch/stem fiber bio composite films were processed by drain casting method. The goals for these productsare to be degradable and decreases the cost of processing, while enhancing the flexibility of the bio-composite films. The effect of fiber content (0, 1%, 2.5% and 4% wt.%) (along with filler saw dust and without it) on the composites in regards to mechanical properties was investigated.

2. Methodology

2.1. Materials

The banana stem had been collected from Rajshahi University of Engineering & Technology (RUET)'s banana garden as shown in Fig.1, and the maize starch had been extracted from the local market's maize. Glycerol and Sodium hydroxide acid were used from the RUET lab and maize starch (homemade).



Fig. 1. Processed raw materials

2.2. Extracting fiber from the banana stem

Fig.2 (b) illustrate dried fiber which is the raw stem, collected from the banana plant. The raw stem was washed and cut into pieces immersed in 2-3% NaOH solution, shown in Fig.2 (a) and heated at 100◦C for the whole night in the oven. The stem pieces became softened and the fiber was eliminated from the waste residue. The fiber was dried in an oven for a whole night at 100◦C. Then the fiber was dried.



(a) **(b)**

Fig. 2 (a) Immersed 2-3% NaOH solution (b) Dried fiber after calcination

2.3. Preparation of starch composite

The composite materials were prepared by the casting process. 0%, 1%, 2.5%, and 4% of stem fiber were used as different sample preparation to understand the right one. A 100 ml beaker was used for the preparation of the solution at which 0% fiber, 2.5% glycerol, 5% starch, and 92.5% distilled water were used for the first sample. It was stirred at 100◦C by a magnetic stirrer in Fig. 3 (a). When it was gelatinized it was cast at a petri dish of 200 mm radius (see Fig. 3 (b)). Then it was dried at 80-90◦C for a night. Then the sample was removed from the petri dish by spatula, shown in Fig. 4. Through this process, the other sample was prepared where only one change was taken which is the increasing of stem percentage and the decreasing of water percentage.



(a) **(b)**

Fig. 3 (a) Stirring the sample in a magnetic stirrer (b) drying at 80-90◦C in an oven



Fig. 4. The sample was placed in a 200 mm Petri dish and safely removed by a spatula

2.4. Preparation of starch composite with filler materials

Saw dust has been used as a filler material for strengthening the composite material. At a 200 ml beaker 5% starch material, 2.5% stem fiber, 2.5% sawdust, 2.5% glycerol and 87.5% distilled water have been stirred by a magnetic stirrer at 100◦C. When it has become gelatinized then the sample has been taken to a petri dish. After that, it has been dried at 90◦C overnight (see Fig. 5).



Fig. 5. Composite after adding filler

3. Characterization

Given the need to elucidate the structural properties of the materials, X-ray diffraction (XRD) analysis was employed to characterize the crystallographic features of the bio-composites. For assess the mechanical properties, tensile testing was performed using a universal testing machine (UTM). The specimens were prepared and cut according to ASTM-D3039 standards to ensure consistency and reliability in testing procedures. Dongguan ZONHOW model number DZ-101 is mainly used to determine the mechanical strength and elongation behavior under applied loads. In addition to mechanical testing the porosity of the samples was measured which can give relevant information of the samples and its potential impact on practical applications.

3.1. Scherrer equation of crystallite size

The Scherrer equation is used to estimate the crystallite size of particles in a material from X-ray diffraction (XRD) data. The equation is expressed as:

$$\mathbf{D} = \frac{K\,\lambda}{\beta \cos\theta} \qquad [14]$$

Here,

D is Crystallite size (in nanometers)

K is Scherrer constant typically in the range of 0.9 to 1.

λ is wavelength of the X-ray source used, commonly 1.5406 Å for Cu Kα radiation.

β is full width at half maximum (FWHM) of the XRD peak in radians.

θ is Bragg angle, the diffraction angle in radians at which the XRD peak occurs.

3.2. Degree of Crystallinity

It is used to calculate the crystallinity percentage in semi-crystalline materials, especially polymers, by analyzing the X-ray diffraction (XRD). The equation provides the proportion of crystalline regions in relation to the total material structure, distinguishing between crystalline and amorphous phases:

$$\textbf{Crystallinity} = \frac{Area\ of\ the\ crystalline\ peaks}{Area\ of\ all\ peaks\ (\ Crystalline+Amorphous)} \times \mathbf{100} \quad [16]$$

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3.3. Tensile stress and Elongation

Tensile stress is calculated as the force applied on a specimen divided by its original cross-sectional area. It is expressed as:

$$\boldsymbol{\sigma} = \frac{F}{A} \qquad [15]$$

Here, σ is tensile stress (in MPa)

F is the applied force (in Newtons, N), measured by the UTM.

A is original cross-sectional area of the specimen (in square meters, m^2)

Elongation, or strain, measures the deformation of the specimen under load and is calculated as the change in length divided by the original length. It is expressed as:

$$\epsilon = \frac{\Delta L}{L}$$

Here, ϵ is strain (dimensionless, often expressed as a percentage)

ΔL is the change in length (in meters, m)

L is the original gauge length of the specimen (in meters, m)

3***.4. Porosity***

The equation has been used here, porosity = $\{(W_f - W_l) / D_l\} * 100$ [17]

3.5. Water Absorption

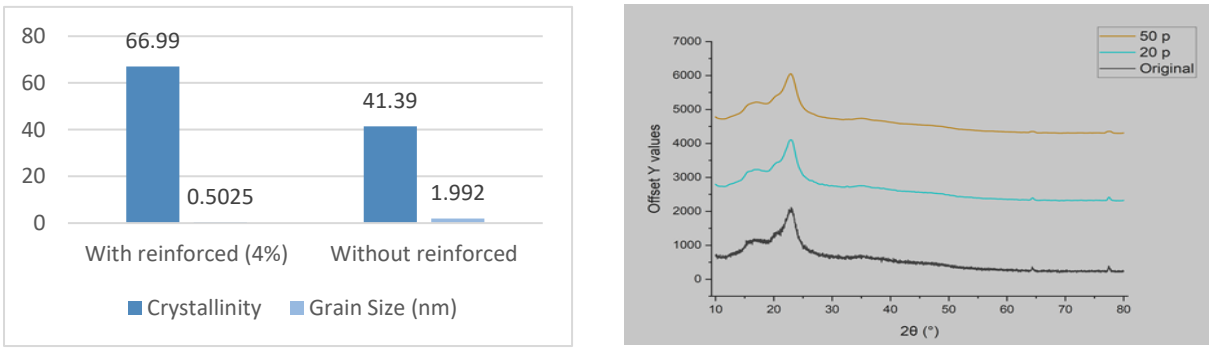
The water absorption is important for a composite material when it is going to be used as packaging material. The water absorption is measured here according to a equation.

$$\text{Increase in weight \%} = \frac{\textit{Wet weight} - \textit{Dry weight}}{\textit{Dry weight}} \times \mathbf{100} \quad [18]$$

4. Result & Discussion

4.1. X-ray diffraction (XRD)

Fig.6, The XRD patterns illustrate the impact of cellulose fiber reinforcement on the structural characteristics of the composite material. The crystallinity was notably increases from 41.39% in the unreinforced sample to 66.99% in the sample with 4% reinforcement in the addition of cellulose which also reflect more ordered molecular structure due to the presence of the fibers. On the other side, the grain size grows significantly from 0.5025 nm in the original sample to 1.992 nm for the attachment of reinforcement. It indicates the development of larger crystalline domains. The area under the crystalline peaks also shows a substantial increase from 6324.44 in the unreinforced material to 11503.56 in the 4% reinforced sample which shows the enhancement in crystallinity. These changes simultaneously suggest that the inclusion of cellulose fibers induces a higher degree of structural organization within the composite which tends to produce better results for well-formed crystalline regions. We can see the crystallite size of maize starch with PVA composite, it has 10.8nm when this has 66.99nm with reinforced agent[1]. Which is much larger than the corresponding one.



(a) **(b)**

Fig. 6. Crystallinity and grain size of with and without reinforced (a) in chart (comparison) (b) in XRD analysis

4.2. Tensile strength

The tensile strength tests were measured by using a Universal Testing Machine (UTM) which show differences, (see Table 1) in mechanical properties depending on the sample type and the inclusion of fillers. The reference sample (4% of reinforced) were cut according to ASTM-D3039 standards which has a width of 25.40 mm, thickness of 3.58 mm and a gauge length of 60 mm and exhibited a tensile stress of 0.148 MPa with an elongation of 2.00% where the peak force was 1.370 kgf. Comparatively, samples reinforced with sawdust were

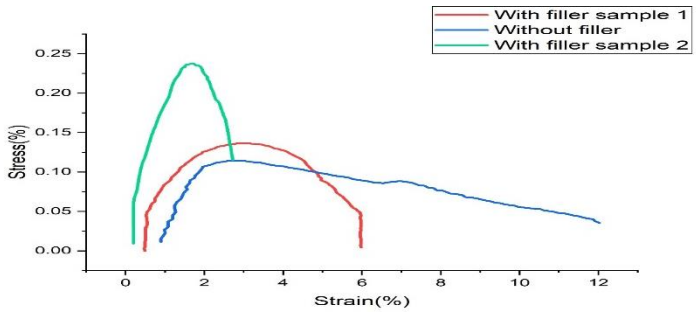


Fig 7. Stress vs Strain curves of with filler and without filler materials

cut according to ASTM-D3039 standards but varied in mechanical performance. The sawdust-reinforced samples had widths ranging from 25.15 to 25.94 mm and thicknesses from 1.70 to 3.58 mm, with tensile stresses measured at 0.140, 0.239, and 0.189 MPa (Fig 7). These variations suggest that both the filler and dimensional properties influence the tensile performance of the materials.

Table 1. *The variations in mechanical properties based on sample type, thickness, and reinforcement, emphasizing the significant tensile strength achieved by the local packaging material.*

Sample type	Width (mm)	Thickness (mm)	Gauge Length (mm)	Tensile Stress (MPa)	Elongation (%)	Peak Force (kgf)
Reference sample (with 4% reinforced)	25.40	3.58	60	0.148	2.00	1.370
Sample with sawdust filler (1)	25.15	1.70	80	0.140	3.145	0.140
Sample with sawdust filler (2)	25.94	2.00	80	0.239	1.622	1.010
Sample with sawdust filler (3)	25.47	2.50	80	0.189	1.490	0.800
Local Packaging Material	25.32	0.53	80	3.166	2.169	4..250

4.3. Porosity

The water bath technique tests the porosity. The porosity is 0.3954. The porosity was measured by taking the sample in a hot water bath for 2 hours and the weighed it. As the initial weight was taken, the difference in the sample's weight was divided by the liquid density and multiplied by 100. That's how the porosity was measured.

4.4. Water absorption

Here, three types of sample water absorption are measured. For 1% stem fiber, 4% stem fiber, and the available local market packaging materials, Table 2., displays the differences in water absorption rates.

Table 2. *Comparison of Water Absorption Rates between Local Packaging Materials and Standard Reference Samples*

Materials Type	Dry Weight (gm)	Wet Weight (gm)	Water absorption (%)
Sample (with 1% reinforced)	1.376	4.066	1.95
Sample (with 4% reinforced)	1.670	5.101	2.05
Local Packaging Material	2.041	9.544	3.676

Based on the information in the table, it's clear that the local packaging materials tend to absorb a lot more water, while our sample shows much better resistance. This comparison is also illustrated in Fig.8.

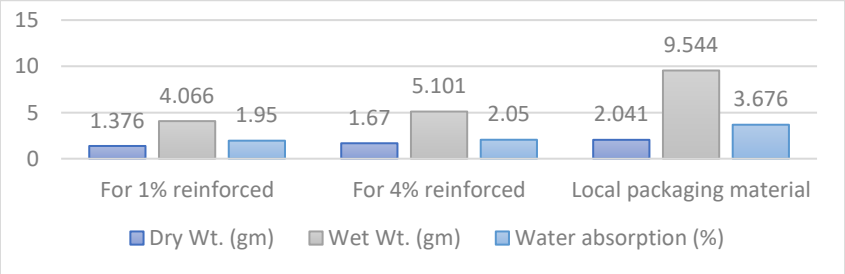


Fig. 8. Water absorption rate according to our sample with packaging materials

It is discussed here about the physical and mechanical properties of the composite material. A better physical property using the banana stem as a reinforcement agent. The characteristics are developed more with the addition of filler material. The tensile strength has been increased than before. As it is compared with the local packaging material, the strength is lesser but the water absorption rate is better. [19], [20], [21] . As for the mechanical properties it is found that without the reinforcement agent, the composite is not even compacted. So it is not possible to determine the mechanical properties. 4% of the fiber is most suitable for composite sample production. Saw dust as an additional material can be used to strengthen the properties. The composite's tensile strength and elongation also directed the effective uses as packaging material. It can withstand load and for its betterment, further research is going on.

5. Conclusion

Imagine a future where every package you touch is gentle on the planet and also not created from harmful petrochemical plastics but from some waste materials given a second life. Nowadays, we strive for a more sustainable world which may reduce plastic use which has become essential. Here, our research explores a biodegradable composite made from banana stem fibers and corn starch as a potential packaging material. Although its strength and durability currently fall short of market standards but adding fillers like sawdust or coconut husk shows promise in enhancing its hardness and tensile strength. The material already has impressive porosity, which enhances its biodegradability—perfect for a world that needs to let go of plastics. This project not only aims to replace plastic but also redefines waste materials as valuable resources. With further development we hope that this composite could offer an effective, eco-conscious alternative and a supporting global effort to reduce plastic dependency and create a greener future.

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