NSEMX_Conf2021_030

The Nigerian Society of Engineers
Minna Branch
1st NSE Minna Branch National Conference 2021

Conference theme
Role of Engineering in Sustainable Development Goals

Thermal and Physicochemical Characterization of Biochar Produced from Waste Bamboo

E. Daniel, P.E. Dim and J.O. Okafor
Department of Chemical Engineering, Federal University of Technology, Minna, Nigeria.

ABSTRACT

This study is aimed at the characterization of biochar produced from waste bamboo using physicochemical and thermal analysis method. The physicochemical result shows that bamboo contains 73.8 % cellulose, 12.49 % hemicellulose, 10.50 % lignin, 0.4 % pectin and 3.20 % aqueous extracts. Thermogravimetric analysis (TGA) was done on raw bamboo waste to determine the temperature of decomposition of bamboo and pyrolysis was done in an inert atmosphere (pure nitrogen) at temperatures of 400 ºC, 450 ºC and 500 ºC to produce the biochar. Proximate and ultimate analysis of the raw bamboo and biochar was carried out and the results showed that the physicochemical properties of the biochar slightly changes as the pyrolysis temperature was increased.

KEYWORDS: *Bamboo; Biochar; Carbon; Proximate analysis; Pyrolysis*

1 INTRODUCTION

Bamboo is one of the strongest and quickest growing trees in the world and have been gaining increasing interest due to its high strength to weight ratio, requires less water, little or no use of pesticides or herbicides and is harvested at its base, leaving the root complete. Also, the tree surface is round and smooth. It is light, harder and stronger than other woods (Pecas et al., 2018). Bamboo has been used in processing abundant and high-quality cellulose fibers for a long time, and has become a major feedstock for weaving, pulp, paper, and in the manufacture of fiber-based composite. The main chemical compositions of bamboo include cellulose, hemicellulose, lignin, all kinds of extracts, a little ash, and silicon dioxide. All of these constituents and properties contribute to bamboo's high strength, bending ductility, toughness and low density (Wang and Chen, 2017). Bamboo is mainly composed of cellulose, hemicellulose and lignocellulose that can be processed into higher value-added products by pyrolysis processes. Furthermore, it possesses many other advantages such as easy cultivation, fast development and low ash content (Mena et al., 2014). Biochar is a carbon-rich solid derived by pyrolysis of biomass with little or no oxygen, Biochar is usually produced from plant residues, wood biomass, animal litters, and solid wastes through various thermochemical processes, including slow pyrolysis, fast pyrolysis, hydrothermal carbonization, flash carbonization, torrefaction and gasification (Tan., et al., 2016). Biochar gotten from biomass is typically 20-40 % of dry lignocellulose biomass. Nonetheless, the yield and chemical properties of the pyrolysis products are firmly impacted by operating conditions during pyrolysis such as temperature, heating rate, holding times, particle size, atmosphere and feedstock. Depending on the final use of biochar, the required properties of the material may be different (Mena et al., 2014). Pyrolysis which is a thermochemical decomposition process, takes place in the absence of oxygen to produce a liquid phase (tar or hydrocarbon liquids and water), a carbon rich solid phase (charcoal) and non-condensable gases (CH_4, CO_2, CO, H_2,), (Mena et al., 2014). Thermo-chemical conversion of biomass is one of the many methods that can be used to convert biomass into valuable products. Pyrolysis, a thermo-chemical process is an effective method with less emission to produce alternative fuels from biomass (Oyedun et al., 2012). The objective of this study is to investigate the thermal and physicochemical analysis of biomass and its product of thermal treatment.

2 METHODOLOGY

2.1. BAMBOO COMPOSITION

The percentage composition of cellulose, hemicellulose, lignocellulose, pectin and aqueous extracts of bamboo waste was determined by acid digestion using a fibre Analyzer. The standard acid digestion fibre (ADF), neutral detergent fibre (NDF) and acid detergent lignin (ADL) analysis were carried out using Ankom 200 Method 5, Method 6 and Method 8 respectively. 0.5 g of ground fibres was used for each analysis. The percentage of cellulose, hemicellulose and lignin content were then determined.

TABLE 1: COMPOSITION OF RAW BAMBOO

CONSTITUENT	COMPOSITION (%)
Cellulose	73.83
Lignin	10.50
Hemicellulose	12.49
Pectin	0.40
Aqueous extracts	3.20

2.2. THERMOGRAVIMETRIC ANALYSIS (TGA)

The TGA of raw bamboo was done using a PerkinElmer TGA 4000 thermogravimetric analyzer and at a heating rate of 10.00 ºC/min to determine the stability temperatures of bamboo during pyrolysis and to determine the temperatures of transitions and reactions of raw bamboo

2.3. PREPARATION OF BIOCHAR

Bamboo was collected from a building site in Minna, Niger state. The sample was cut into small pieces of 6-8 cm in length and washed thoroughly with running water followed with distilled water to remove impurities. The sample was dried in an electric oven at 100 oC for 24 h to reduce moisture content. The dried Bamboo was crushed using a club hammer, it was then reduced further into smaller sizes of length 8-10 mm using a grinding machine. 25 g of the crushed Bamboo was weighed into a crucible and charged into the pyrolysis reactor. The air-lock was closed to avoid the introduction of oxygen. The cylinder containing nitrogen gas was then connected to the pyrolysis reactor and the valve opened with gas flow rate set at 1cm/min. Pyrolysis was done at temperatures of 400 oC, 450 oC and 500 oC for 2 h. The char was then removed from the reactor, air-cooled, weighed and kept for further analysis.

2.4. PROXIMATE AND ULTIMATE ANALYSIS

The proximate and ultimate analysis of Bamboo and Biochar was done to determine their physical and chemical properties. Proximate analysis carried out includes; moisture content (ASTM E1358-97), ash content (ASTM E1755-01), volatile matter (E872-82) and fixed carbon content (ASTM D1762-84) while the elemental analysis includes; percentage carbon, Nitrogen, Hydrogen and Oxygen (C, N, H and O).

3 RESULTS AND DISCUSSION

3.1 COMPOSITION OF BAMBOO

Analysis on the structural composition of Bamboo was carried out on waste stem samples and results showed that the bamboo stem has a very high cellulose content of 73.83 %. Percentage contents of Lignin, Hemicellulose, Pectin and aqueous extracts are 10.50 %, 12.49 %, 0.40 % and 3.20 % respectively as shown in table 1. These are in the range of hard wood biomass as reported by (Amaral and Leite., 2014). A high percentage of cellulose in biomass suggests more volatilization during pyrolysis as both the polysaccharide structures are broken down at a lower temperature range of 200-400 oc. This is in conformity with the findings of (Sahoo et al., 2021).

3.2 THERMOGRAVIMETRIC ANALYSIS (TGA)

Thermal analysis was carried out using 10 mg of raw bamboo samples at a constant heating rate of 10 oC/min from room temperature up to 850 oC. The TGA shows the thermal degradation steps, the first TG curve corresponds to drying and dehydration between the temperature range of 30 – 100 oC. The second curve between the temperature range of 250-400 oC corresponding to weight losses as a result of Hemicellulose and cellulose degradation (Mena et al., 2014). At temperatures higher than 400 oC, almost all cellulose was pyrolyzed. Lignin decomposes slowly all through the temperature range from room temperature to 850 oC which correlates with the findings of (Mahanim et al., 2011). In general, pyrolysis of wood biomass takes place in a step-wise manner with Hemicellulose breaking down first, cellulose next and then Lignin. This is shown on figure 1.

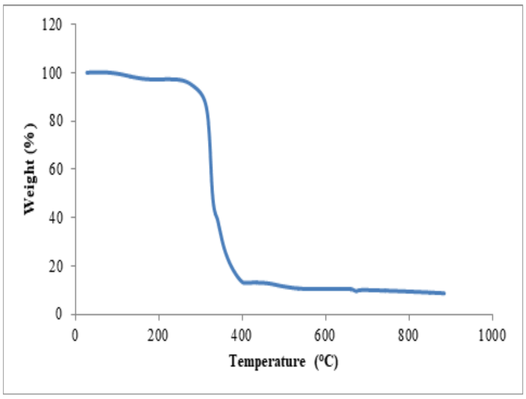

FIGURE 1: TGA THERMOGRAM OF RAW BAMBOO

3.3. PROXIMATE AND ULTIMATE ANALYSIS

The proximate analysis of raw bamboo was based on the ASTM standards methods (ASTM E871-82, ASTM E1755-01, and ASTM E872-82). This was to determine the moisture content, ash content, volatile matter and fixed carbon. The proximate and ultimate analysis of bamboo is shown in Table 2, the high percentage of Volatile matter, high fixed carbon, low moisture and ash content meets the criteria of bamboo to be utilized as feedstock for the production of biochar. Lower moisture contained in the bamboo implies less energy requirement, low biomass consumption for the pyrolysis process and greater biochar yield. So biomass with a low percentage of moisture content is the most preferable feedstock for the production of biochar which correlates with the findings of (Canal et al., 2020). The biochars produced at pyrolysis temperature of 400 oc had a somewhat higher volatile matter as a result of incomplete carbonization. The percentage ash content in the biochars slightly increased as the pyrolysis temperature is increased. However, the percentage fixed carbon had no significant difference in all the biochars. This may be as a result of escape of some carbon in the form of volatile matter as the pyrolysis temperature is increased. These results are in conformity with the findings of (Sahoo et al., 2021). It can be observed that raw bamboo contained predominantly volatile matter which is expected to decompose during pyrolysis. Low percentage of moisture content was as a result of the samples being dried before pyrolysis. Elemental analysis of raw bamboo as shown in Table 2 indicates a high percentage of oxygen and carbon which are the main constituents of plant fibres. Proximate and ultimate analysis of biochar was conducted at reactor temperatures 400 oc, 450 oc and 500 oc. There is a decrease in moisture content and volatile matter as a result of continuous decomposition of these components as the pyrolysis temperature is increased, this invariably lead to an increase in the percentage ash content.

TABLE 2: PROXIMATE AND ULTIMATE ANALYSIS OF RAW BAMBOO

Proximate and Ultimate analysis	Composition (%)
Moisture Content	10.24
Ash content	1.85
Volatile Matter	74.15
Fixed Carbon	14.73
Carbon	38.50
Nitrogen	0.52
Hydrogen	5.40
Oxygen	53.50

TABLE 3: PROXIMATE ANALYSIS OF BIOCHAR

Pyrolysis Temp °C	Moisture content (%)	Ash content (%)	Volatile Matter (%)	Fixed Carbon (%)
400	1.90	3.05	49.40	45.65
450	1.54	3.26	49.30	45.60
500	1.38	3.56	49.10	46.96

TABLE 4: ULTIMATE ANALYSIS OF BIOCHAR

Temp. °C	C (%)	H (%)	N (%)	O (%)
400	54.82	6.18	0.24	15.06
450	50.62	5.03	0.25	10.45
500	56.48	3.88	0.22	6.37

4 CONCLUSION

Biochar from bamboo waste was subjected to pyrolysis at different temperatures of 400 °c, 450 °c and 500 °c. Physicochemical analysis showed a slight change in properties with increase in pyrolysis temperature. The waste bamboo biochars shows suitable properties for its application in reinforcements, as energy source and agricultural applications.

REFERENCES

Amaral, S., & Leite, L. (2014). Comparative Study for Hardwood and Softwood forest Biomass; Chemical Characterization, combustion phases and gas and Particulate Matter Emissions. Bioresource Technology, Vol. 164, pp. 55-63.

Canal, W.D., Carvalho, A.M.M., Figueiro, C.G., Carneiro, A.D.C.O., Fialho, L.D.F., Donato, D.B. (2020). Impact of wood moisture in charcoal production and quality. Florest. Ambient. 27 http://doi.org/10.1590/2179-8087.099917.

Mahanim, S.M.A., Asma, I.W., Rafidah, J., Puad, E., & Shaharuddin, H. (2011). Production of Activated carbon from Industrial bamboo wastes. Journal of Tropical Forest Science 23(4): 417-424

Mena. L., Pecora. A., & Beraldo. A. (2014). Slow pyrolysis of Bamboo Biomass: Analysis of Biochar properties. Chemical Engineering Transactions, 37, 115-120. DOI:10.3303/CET1437020

Oyedun, A., Gebreegziabher. T., & Hui. C. (2012). Mechanism and Modeling of bamboo pyrolysis. Fuel processing Technology. DOI:10.1016/j.fuproc.2012.09.031

Pecas, S., Carvalho. H., Salman. H. & Leite. M. (2018). Natural fibre composites and their Applications: A Review. Singh, A.P., Causin, V., Nuryawan, A., & Park, B. (2014). Morphological, chemical and crystalline features of Journal of composites science 2,66.

Phuakpunk, K., Chalermsinsuwan, B., & Assabumrungrat, S. (2020). Pyrolysis Kinetic Analysis of Biomasses: Sugarcane Residue, Corn Cob, Napier grass and their mixture. ENGINEERING JOURNAL Volume 24 Issue 4. DOI: 10.4186.

Sahoo, S., Vijay, V., Chandra, R., & Kumar, H. (2021). Production and Characterization of Biochar produced from slow Pyrolysis of Pigeon pea stalk and bamboo. Cleaner Engineering and Technology 3(2021) 100101.

Tan, x., Liu, Y., Gu, Y., Xu, Y., Zeng, G., Hu, X., Liu, S., Wang, X., Liu, S., & Li, J., (2016). Biochar based nano composites for the decontamination of wastewater: A review. Bioresource Technology (2016), doi:http://dx.doi.org/10.1016/j.biortech.2016.04.093.

Wang. G. & Chen. F.(2017). Development of Bamboo fibre-based composites. International centre for Bamboo and Rattan, Beijing, China.