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Production and characterization of black charcoal from *Bambusa vulgaris* (Yellow Bamboo) and potentiality for advance applications

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Abstract: Issues of air and water pollution and necessity of health care are becoming serious problem as the inter country and global industrialization accelerates. Finding solutions and speedy addressing to these problems via sustainable management and expansion of woody and non woody forest crops, extraction, eco and health friendly products development is increasingly important. Environmentally and health friendly bamboo charcoal has greater potential and upcoming demand in the globe. Evaluation of higher carbonation temperature and characterization of charcoal properties compared to traditional carbonation temperature pave the way for modification of surface and absorbance properties of bamboo charcoal and expansion of areas applications. This paper provides a scientific research about the optimum carbonation temperature to produce charcoal from *Bambusa vulgaris* (yellow bamboo). The bamboo culm was carbonized at four differed temperatures ranging from 600 to 950°C. Products of charcoal were characterized by SEM micrograph analysis, modules of rupture (MOR), calorific value, density, bulk density, density determination and water absorption determination. Optimum carbonization temperature to gain maximum property enhancement of bamboo charcoal was observed around 700 and 850 °C. By changing carbonization temperature charcoal properties can be change. Removal and solidification of carbon in the flue gas during manufacturing and convert into usable foam of product development pave the way for the expansion of charcoal manufacturing industry without harmful damage to the environment.

Keywords: Sustainable management, Yellow bamboo charcoal, Carbonation temperature

1.0 Introduction

Sri Lanka is presently one of the world's dominant exporters of tea, rubber, coconut, perishables, and spices. Upcoming material manufacturing industries also add an extra value to the growing economy. In order meet the demand of industrialization agro-industry policy planning emphasized to utilize high yielding agro – raw materials to use as an input to advance manufacturing industry and promote cyclic agriculture and small and medium manufacturing enterprises. The fast-growing renewable resource of bamboo normally achieves its maturity after 4 years with the highest volume weight and mechanical strength, thus it is the most suitable age for bamboo industry. Bamboo has massive positive impact to the environment as well as to the economy of the rural communities by opening up a cluster of advanced manufacturing industry. Cultivation and economical perspectives of bamboo in Sri Lanka is still in a poor condition. With this non visionary approach bamboo is grown in ornamental purposes as well as some traditional perspectives such as river bank conservation, ornamental artifact production and as a building material. There are several initiatives to establish plantation and manufacturing industrial items. For a targeted development, a national road map and strategic plan development has been initiated recently to switch and promote cottage industry to advance material product manufacturing. Thus, mix cultivation to increase the plantation extent for both supplying raw materials and win- win effect of economical and ecological consideration. Charcoal and activated carbon production is one of the most important developing manufacturing practice of bamboo across the bamboo growing regions in the globe. Adsorption, separation and capture of various greenhouse gases using charcoal and activated carbon is an emerging technology [1, 2,3, 4, 5, 6,). There is a high potential of charcoal use in domestic water purification and filtration, environment purification system by capturing CO_2 emission and advanced industry application [7]. Series of advance products can be manufactured on the basis of the supreme absorption function, electromagnetic shielding and far infrared creation of the bamboo charcoal, however, are still under research.

There are more than 1300 species of bamboo across the globe and more than 14 prominent species are in Sri Lanka and out of these 6 species are endemic. Most prominent bamboo species in Sri Lanka is identified as Bambusa vulgaris and two different types are commonly presence namely, yellow and green bamboo. This variety has some pitfalls to prepare some products because of lesser durability due to insect and fungal attacks. Non-straightness of the culms is a critical barrier resulting of high wastages when make use as a raw material for industry item and preparation of wood panel panels. *Bambusa vulgaris* showed maximum carbonization yield [2]. Bamboo based black charcoal has high carbon content, high strength and comparative good properties than white charcoal. Main difference of the white charcoal and black charcoal is based on the firing technique and it has high improvement in the considered properties and appearance of the resultant charcoal. White charcoal is generally prepared using high oxygen air-circulating kilns and resultant charcoal yield and purity is minimal compared to black charcoal. The black charcoal is simply expressed as "baked charcoal" and its properties and yield is higher than the white charcoal.

The present study focuses to characterize bamboo charcoal produce at four identified carbonization temperatures and select the best temperature to produce high quality black charcoal. Development of yellow bamboo culm based black charcoal were produced in a laboratory scale furnace with an inner steel vessel (tort) with an external heating and properties of black charcoal were evaluated and compared for different applications.

2.0 Experimental procedure

2.1 Materials preparation

Matured bamboo culms in four years' maturity of variety *Bambusa vulgaris* was harvested from Colombo area, Sri Lanka. Bamboo culms were spilt and plain to remove outside silica rich layer and inside powder layer. Prepared bamboo culm strips were dried in an electrical air-circulating oven (Make: Memmort) at 110 ± 2°C for 24 hours. A proximal analysis was performed to standardize raw materials: moisture, ashes, volatile matter, fixed carbon and waxes. SEM micrograph analysis was carried out for both cross sectional and longitudinal views.

2.2 Carbonization

Dried bamboo strips were tightly packed in steel vessel which has a small hole on the lid to expel smoke and gases produced when firing of bio-mass. Bamboo packed steel vessel was placed in a tube furnace (Make: Elite, Model: TMH 12/ 75/ 750 3x 2416) and fired at four different temperatures varying from 400 to 950°C. The temperature of the furnace was increased from room temperature to target temperature with a temperature gradient of 15°C/ minute and maintain at the same for 2 hours. Temperature of the furnace allowed to naturally cooled down. After reach to the room temperature the vessel was removed from the furnace and charcoals were collected.

2.3 Characterization methods

2.3.1SEM micrograph analysis

Micromorphological characteristics of bamboo culm before and after carbonation were determined by SEM using LEO 1420 VP model.

2.3.2 Modulus of rupture (MOR) of charcoal

The six pieces of rectangular shaped bamboo charcoal planks has regular planer dimensions were selected for MOR study from each treatment temperature. Length, breadth and height of the piece were determined three places of a charcoal piece. Then the charcoal piece was placed on the two supports having distance of 75 mm of the force meter (Make: Com-Ten Digital Force Meter Model: DFM 5000). Then speed was set as 5% of maximum scale and operates to compress by the middle support bar, until sample breaks. The maximum breaking force was recorded and MOR value per piece was calculated using following equation.

$$MOR = ((3FL)/(2wh^2))$$

Where, F- Breaking force in Newton

L- Distance between two supports in mm

w- Average width of the test piece in mm

h- Average height of the test piece in mm

2.3.3 Density of charcoal

Density of the bamboo charcoal pieces were determined using Sartorius specific gravity balance. The initial weight of oven dried (110 ± 2 °C for 24 hours) charcoal piece was measured at air and in the water. The specific gravity was determined after completion of water absorption. Results were interpreted as Density of charcoal.

2.3.4 Bulk density of charcoal

Bulk density of the charcoal was carried out through laboratory developed protocol. Charcoal sample was oven dried (110 ± 2 °C for 24 hours) and finely ground. Five grams of ground charcoal was filled into a measuring cylinder and compacted by tapping 20 times by plastic ruler. The resultant volume was recorded and bulk density was calculated.

2.3.5 Calorific value of charcoal

Calorific value of the charcoal was determined through bomb calorimetric method (Make: Gallencamp) using the standard protocol.

2.3.6 Water absorption of charcoal

Pre weighed oven dried (110 ± 2 °C for 24 hours) charcoal piece and ceramic pebble was enclosed in tea-bag pouch and sealed using polythene sealer. Then sample was to sink in water for 24 hours. After the soaking period charcoal piece was mopped and weighed to get absorbed weight. Water absorption was calculated as a percentage of absorbed weight.

2.3.7 Data analysis

Data was analysed using IBM SPSS software version 20. The post hoc mean separation was carried out using Tukey's HSD test method. Three replications were made.

3.0 Results and discussion

The properties of bamboo black charcoal were determined to identify their potentials on various industrial applications of absorbents, fillers, fuel and value added applications. The proximal analysis % of Bambusa vulgaris (yellow bamboo) revelled that this species shows characteristic composition observed in most of the lignocellulose materials [2]. The high content of volatile matter and low amount of ash suggest that the bamboo structure is appropriate to obtain charcoal and activation [3].

3.1 Microstructure images of charcoal and analysis

SEM was used to study changes in morphology in the materials during four different carbonation temperatures.

Fig. 1.A, B, and C shows the characteristic morphology associated to the cellulose fibres as structure of the raw *Bambusa vulgaris* (Yellow bamboo). The micrographs corresponding to the sample after the application of thermal treatments in Fig. 2 A, B, C and D show the conservation of the shape of the cellulose – based materials with more opening of microspores. This carbonaceous material seems to honeycomb like structures as result of the elimination of organic and volatile compounds during the thermal decomposition and semi activation process during carbonation. Bamboo charcoal showing more microspores and interconnected countless small cavities and pore volume compared to other lignocelluloses materials. Compared to wood charcoal, bamboo charcoal has about four times more cavities and adsorption rate. In terms of surface area, bamboo charcoal's $300m^2/g$ is ten times more than wood charcoal's $30m^2/g$ which is an excellent texture for absorbance properties as a precursor for activated carbon.

The MOR is the measure of the strength of charcoal for various applications high mechanical stability. Density and bulk density data are useful for filler and fuel applications. Calorific value is the measure of energy producing ability of the charcoal material. The resulted values are given in Table 1.

The results show statistically significant variation of MOR, density and % water absorption with the carbonation temperature. Highest value of MOR showed charcoal produced at 700 °C. There is a trend of increment of density up to 850 °C and significant trend of reducing of % water absorption with the increasing of carbonization temperature (Table 1).

Bulk density of the prepared bamboo charcoal (Fig. 3) increased with processing temperature. It may happen due to sintering of charcoal material in a condensed form with the temperature. It also has an effect of the increment of strength, hydro-phobic nature with processing temperature increases.

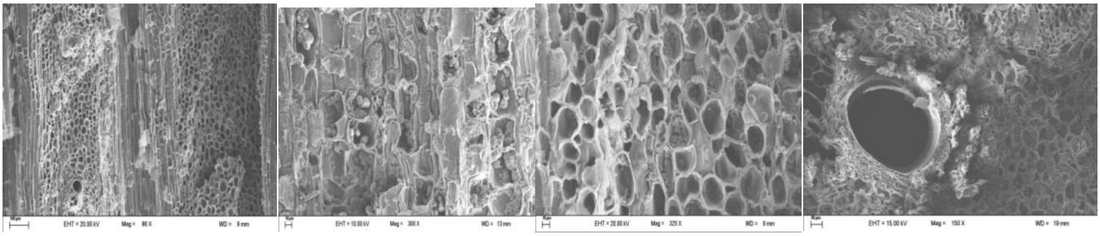

Figure 1.A Figure 1.B Figure 1.C

Figure 1 Microstructure images of species of *Bambusa vulgaris*

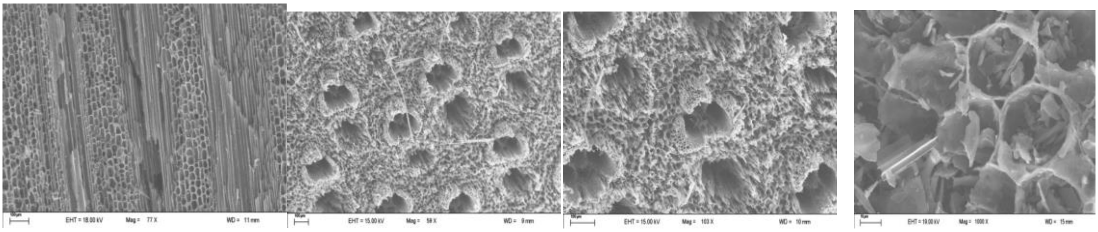

Figure 2.A Figure 2.B Figure 2.C Figure 2.D

Figure 2. Microstructure images of charcoal produced from *Bambusa vulgaris*

Table 1. Characteristics of the bamboo black charcoal produced at four different temperatures

Processing temperature	MOR / (Nmm^{-2})	Density/ ($g\ cm^{-3}$)	% water absorption at soak (after 24 hours)
600 °C	3.11 ± 0.87^{b}	0.29 ± 0.02^{b}	217.92 ± 12.23^{a}
700 °C	11.28 ± 2.95^{a}	0.36 ± 0.01^{b}	189.34 ± 6.92^{a}
850 °C	5.03 ± 1.07^{ab}	0.50 ± 0.04^{a}	92.72 ± 4.04^{b}
900 °C	4.02 ± 0.98^{b}	0.32 ± 0.03^{b}	123.32 ± 13.1^{b}

Maximum pore distribution, strength, bulk density, density and hydrophobic nature of the bamboo charcoal clearly indicated that overall charcoal property enhancement can be obtained in-between 700 and 850 °C carbonation temperature. It is reported that factor determines the carbonization yield is the temperature and highest yields at 400 °C. Total conversion of the bamboo species into carbonaceous materials is achieved at 350°C and at 400°C, the total elimination of the volatile species from bamboo has been produced [2]. Results obtain from the present study revelled that charcoal yield obtained at 700 and 850 °C carbonation temperatures ranges from 27-33%. The yield of bamboo charcoals almost constant between 500°C and 900 C [1]. This indicated that production of bamboo charcoal is economically feasible due to this high conversion ratio. Calorific values of bamboo charcoal obtained at this same range of carbonization temperatures varied from 6900 – 7500 kcal/ kg indicating the high energy content of the material as a fuel material. The sorption capacity of porous carbon depends on surface area, pore structure and functional groups on its pore surface. Basically, the functional groups and pore structure determines the application of porous carbon materials for different uses. Bamboo carbonized at 600 °C had the best Brunaure – Emmett - Teller (BET) specific area compared to 400 °C carbonization temperatures [8]. Terminal carbonization temperature most significantly affected bamboo charcoal quality and properties compared to terminal pyrolysis temperature, carbonization speed, bamboo moisture content, and bamboo dimension [9]. Adsorption capacities of bamboo charcoal and activated carbon with microspore, mesopore, and macrospore distributions based on different functional groups of bamboo charcoal. Benzene, toluene, indole, skatole, and nonenal removal effects were the highest for the bamboo charcoal carbonized at 1000°C and tended to increase with increasing carbonization temperature [10].

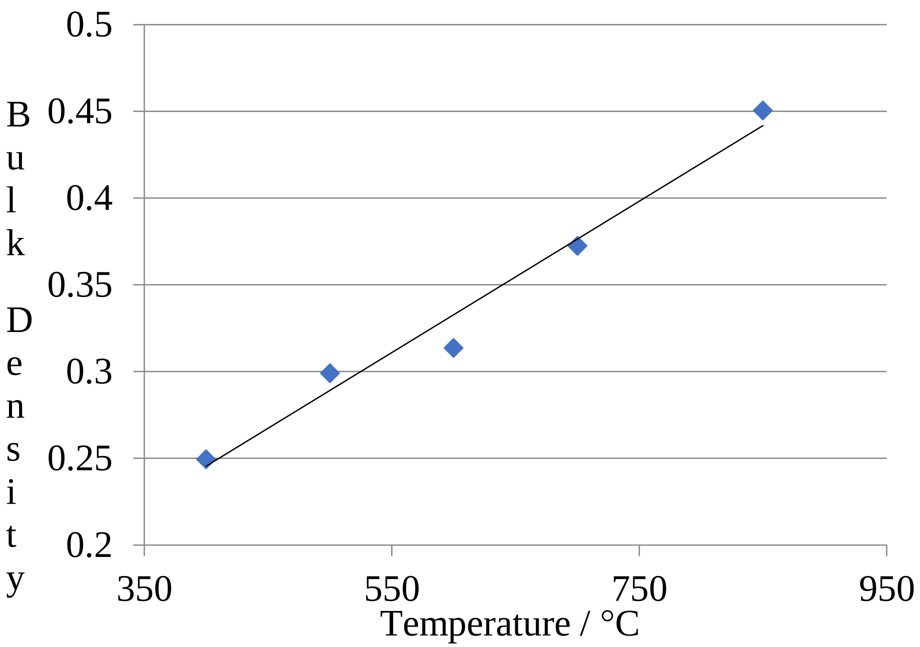

Figure 3. Bulk density of the bamboo charcoal with processing temperature

Functions of deodorization, dehumidifying, prevent mildew formation, antibacterial and anti-dust, mites and insects, release far infrared rays and negative ions and absorbs electromagnetic waves to promote blood circulation and metabolism, water purifying and release natural minerals, skin care and body beauty products development are key areas to promote bamboo charcoal. As the global industrialization accelerates, the issues of air and water pollution are becoming increasingly serious. Bamboo charcoal is a new environmentally friendly material which has greater potential and demand in the world due to declining of wood resources to produce high quality charcoal, fast growing ability and short in harvest cycle, renewability. Properties of bamboo charcoal are similar to those of charcoal made from hardwood and ideal substitute for to quality wood charcoal. There is an extensive use of activated carbon for the wastewater treatment and other adsorption treatments. However, the production process of activated carbon still remains as an expensive process. This fact has prompted a growing interest into the production of low cost activated carbons by using low cost precursor like bamboo charcoal. Thus the high degree of hardness of bamboo charcoal and high quality black colour tunnel like charcoal culms can be used to manufacture high quality crafting items and daily consumption items. Bamboo charcoal is of good electromagnetic shielding property and releasing of far infrared ray's ability still are under research. Currently, series of products are being manufactured on the basis of the supreme absorption function and far infrared creation of the bamboo charcoal.

Removal and solidification of carbon in the flue gas during manufacturing of charcoal and convert into usable foam of product development pave the way for the expansion of charcoal manufacturing industry at different scale from micro to large scale enterprises without harmful damage to the environment.

4.0 Conclusions

Issues of air and water pollution and necessity of health care are becoming serious problem as the inter country and global industrialization accelerates. Finding solutions and speedy addressing to these problems via sustainable management and expansion of woody and non woody forest crops, extraction, eco and health friendly products development is increasingly important. New environmentally and health friendly bamboo charcoal has greater potential and upcoming demand in the globe. Evaluation of higher carbonation temperature and characterization of charcoal properties compared to traditional carbonation temperature pave the way for modification of surface and absorbance properties of charcoal and expansion of areas applications. Optimum carbonization temperature to gain maximum property enhancement of bamboo charcoal was observed around 700 and 850 °C. However, by changing carbonization temperature charcoal properties can be change to meet functional requirements of the end product.

References

[1] R. Wang, Y. Amano, M. Machida, Surface properties and water vapor adsorption–desorption characteristics of bamboo-based activated carbon, *J. Anal. Appl. Pyrol.,* 104 (2013) 667-674.

[2] P.G. Gonzalez, Y.B. Pliego, Physicochemical and microtextural characterization of activated carbons produced from water steam activation of three bamboo species, *J. Anal. Appl. Pyrol.,* 99 (2013) 32-39.

[3] P.G. Gonzalez, T. Hernandez, L. Garcia, The use of experimental design and response surface methodologies for the synthesis of chemically activated carbons produced from bamboo, *Fuel Process. Technol.,* 127 (2014) 133-139.

[4] Q. Liu, T. Zheng, P. Wang, L. Guo, Preparation ad characterization of activated carbon from bamboo by microwave-induced phosphoric acid activation, *Ind. Crops Prod.,* 31 (2010) 233-238.

[5] Y. Zhang, Z. Xing, Z. Duan, M. Li, and Y. Wang, Effects of steam activation on the pore structure and surface chemistry of activated carbon derived from bamboo waste, *Appl. Surf. Sci.,* 315 (2014) 279-286.

[6] Y.X. Wang, H.H. Ngo, W.S. Guo, Preparation of a specific bamboo based activated carbon and its application for ciprofloxacin removal, *Sci. Local Environ.*, 533 (2015) 32-39.

[7] P.H. Huang, J.W. Jhan Y.M. Cheng, H.H. Cheng, (2104) Effects of carbonation parameters of Moso- Bamboo –Based porous charcoal on capturing carbon Dioxide, *The Scientific World Journal*, Volume 2014 (2014), Article ID 937867, 8.

[8] F.L. Lan, H.L. Lay, W.F. Teng, Study on the moso bamboo charcoal property, *Crop, Environ. Bioinformatics, 5* (2008) 180-186.

[9] S. Jiang, (2004) Training Manual of Bamboo Charcoal for Producers and Consumers, Bamboo Engineering Research Center, Nanjing Forestry University.

[10] T. Asada, S. Ishihara, T. Yamane, A. Toba, A. Yamada, K. Oikawa, Science of bamboo charcoal: study on carbonizing temperature of bamboo charcoal and removal capability of harmful gases, *J. Health Sci.,* 48(6) (2002) 473–479.

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