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Chemical, strength and microstructure characterization of Balinese bamboos as activated carbon source for adsorbed natural gas application

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Abstract. Bamboo is one of promising biomass raw materials that has been widely researched, developed, manufactured as activated carbon (AC) and applied in many fields of life. However, there were only a few references associated to the use of bamboo AC as an adsorbent for Adsorbed Natural Gas (ANG) application. The purpose of this study was to characterize chemical, strength and microstructure of two types of local Balinese bamboo that were Tabah bamboo (Gigantochloc Nigrociliata) and Tamblang bamboo (Schizostachyum Brachycladum) as AC source. Characterization was carried out by undertaking proximate, ultimate, tensile tests, Van Soest analysis and microstructure observation. The results have showed that Tabah bamboo has 22.9151 % lignin, 44.9456 % cellulose, 84.56 % volatile and 44.47 % carbon, which were those characteristics higher than Tamblang bamboo. Furthermore, Tabah bamboo also has higher bond density vascular bundles, higher tensile strength (240.85 ± 17.53 Nmm-2) and fracture strength (182.39 ± 17.46 Nmm-2), lower ash (2.92 %), silica (1.84 %) and nitrogen (0.95 %) compared to Tamblang bamboo. Due to such characteristics, Tabah bamboo has greater potential as an AC precursor than Tamblang bamboo.

1. Introduction

Activated carbon (AC) is carbon material having a high porosity [1], high adsorption capacity [2], high mechanical strength [3] and a very large surface area [4]. Activated Carbons (ACs) are widely used in industry such as to separate the various types of pollutants such as dyes and metal ions from industrial waste [5], as gas storage [6-10] and others. Commercial ACs are generally derived from coal which is a non-renewable carbon source with relatively expensive price [11]. As an alternative, it has been extensively researched and developed ACs from biomass, such as coconut shell [12-13], palm [14], and bamboo [5, 14-17].

Bamboo is a biomass material widely studied as a source of activated carbon. Its growth is very fast; maximum altitude can be reached in just a few months [18] and matures in three years. Bamboo constitutes a tropical plant and grows naturally in all continents except Europe [19]. In Asia, bamboo grows in China, Thailand, Vietnam [20] and Indonesia. It can be converted into activated carbon through carbonization and activation processes. Carbonization process is intended to enrich material carbon content by eliminating non-carbon elements using thermal decomposition [21] and to reduce the content of volatile and converting into char with higher fix carbon content. While the purpose of activation (physical or chemical activation) is to develop advanced porosity and to produce regular structure that will eventually form the high porosity of solid activated carbon [7].

Some researchers have developed bamboo ACs for various applications such as for separation of heavy metals [22], for purification of waste water [14], as a cathode material of super capacitor [17] and others. Although bamboo ACs have been studied and applied in many fields, almost no references were found relating to their application as an adsorbent for ANG. In ANG technology, adsorbent serves to stored methane gas. Methane gas molecules caught inside the pores of the adsorbent due to their strong surface tension force (Van der Walls force). Distance molecules in the pores of the adsorbent is much closer than in the gas phase at the same pressure and temperature that causes the density of the methane molecules in the adsorbed phase become like liquid phase and has a greater density than the gas phase at equilibrium condition. The result is an increase in the fix volume of the system adsorption due to larger amount of adsorbed gas than the volume gas which was replaced by adsorbent [23]. As an ANG adsorbent, ACs must have high micro pore and large surface area. As a material source of ACs, bamboo has great properties to fulfil those requirements. It has high carbon content (48.64 %) and low contents of nitrogen (0.14 %), sulphur (0.11 %) and hydrogen (6.75 %) [24]. The chemical compositions of bamboo are similar to wood with containing cellulose, lignin and hemicellulose more than 90% of its total mass. In general, the content of alpha cellulose of bamboo is 40-50%, while the content of alpha cellulose of softwood and hardwood are 40-52 % and 38-56 %, respectively [25]. The lignin content of bamboo ranges from 20% to 26%. With such chemical compositions, bamboo has a good criterion as a raw material of ACs. Bamboo-based activated carbon has four times bigger micro pore and 10 times greater surface area when it is compared to carbon-based wood [26]. In addition, bamboo is very easy to find and has a short cutting-age cyclic (3-5 years) [25]. One of the factors affecting the characteristics and qualities of ACs is the chemical compositions of raw material used. In this study, the preliminary characterization and evaluation of two types of Balinese bamboo were carried out.

2. Method

The biomass raw materials used were two local Balinese bamboos: Tabah bamboo (*Gigantochloc Nigrociliata*) and Tamblang bamboo (*Schizostachyum Brachycladum*). Bamboo was cut into small pieces, dried during 10 days under the sunshine and heated in the electric furnace for 1 hour at a temperature of 110^0 C until no changes in weight. Specimens were formed into powder each 10 grams for chemical composition, proximate and ultimate tests. Proximate test was carried out by using TGA 701, 0.02 % RSD Precision to find out of moisture, volatile, fix carbon and ash of both bamboos. The ultimate test was based on ASTM D7582 Biomass and using CHN628S machine to investigate the contents of carbon, hydrogen and nitrogen of the raw materials. Van Soest Analysis, also known as USDA (United State Department of Agriculture), was used to determine the content of lignin, hemicellulose, cellulose and silica. Tensile test was based on ASTM D 143-94 using hydraulic tensile machine with a capacity of 3,000 kg. In order to observe microstructure, bamboo was cut to size 2 x 1 cm, polished, etched and observed by using Microscope Optic (10-1,200 optical zoom).

3. Results and discussion

3.1. Chemical compositions

Chemical compositions of both bamboos are presented in table 1. It can be seen that the main content of bamboo was composed by cellulose, hemicellulose and lignin. Tabah bamboo contained 44.94 % cellulose that higher than the Tamblang bamboo, which was 42.52 %. Tabah bamboo also contained higher hemicellulose and lignin than Tamblang bamboo but it implied lower silica. Some researchers had carried out the chemical composition test of different types of bamboo. Scurlock et al reported the cellulose content of a Japanese bamboo around 43.30 % [27]. This result was close to the cellulose value of Tabah and Tamblang bamboos. Li et al examined the cellulose content of bamboo taken from Kisatchie National Forest, Louisiana, USA and obtained value in the range of 46.08 - 47.91% [25].

Luz et al [28] got the cellulose content of 4 types *Guadua* bamboo (*Macana*, *Cebolla, Rayada and Castila*) varies from 37% to 44%. These values were also similar to cellulose content of Tabah and Tamblang bamboos.

Table 1. Chemical compositions of tabah and tamblang bamboos

Materials	Hemicellulose (%)	Lignin (%)	Cellulose (%)	Silica (%)
Tabah bamboo	16.99	22.91	44.94	1.84
Tamblang bamboo	16.73	21.23	42.52	1.96

3.2. Proximate and ultimate analysis

Table 2 shows the results of proximate and ultimate analysis of both bamboos. Tabah and Tamblang bamboos have a fix carbon 3.22 % and 4.61 %, respectively. Fix carbon is a carbon that still bound by the binding elements such as H, N and O. The ultimate analysis showed that Tabah bamboo contained higher carbon (42.47 %) than Tamblang bamboo (41.26 %). The increase of these carbons due to elements such as H, N and O separated from fix carbon during ultimate analysis. Furthermore, after the carbonization and activation processes, the fix carbon and carbon content are expected to increase. The volatile content of Tabah bamboo (84.56 %) was higher than Tamblang bamboo. Meanwhile, Tabah bamboo contained lower ash (2.92 %) and nitrogen (0.95 %) than Tamblang bamboo and relatively had almost the same hydrogen content. Low ash content will result in minimal effect of impurities on the formation of pores during the activation process. According to Mahamin et al, a good activated carbon source should be low ash and high carbon and volatile [15]. Ash consists of mostly minerals such as silica, alumina, iron, magnesium and calcium that are undesirable due to all of them are impurities. In general, a material with the lowest ash content will generate the most active carbon [15].

Table 2. Proximate and ultimate analysis of tabah and tamblang bamboos

Materials	Moisture (%)	Volatile (%)	Ash (%)	Fix Carbon (%)	C (%)	H (%)	N (%)
Tabah bamboo	9.27	84.56	2.92	3.22	42.47	6.10	0.95
Tamblang bamboo	7.67	83.48	4.26	4.61	41.26	6.09	1.03

Table 3. Ultimate and fracture strength of tabah and tamblang bamboos

Materials	Tensile strength (Nmm^{-2})	Fracture strength (Nmm^{-2})
Tabah bamboo	240.85 ± 17.53	182.39 ± 17.46
Tamblang bamboo	185.24 ± 20.58	112.98 ± 19.88

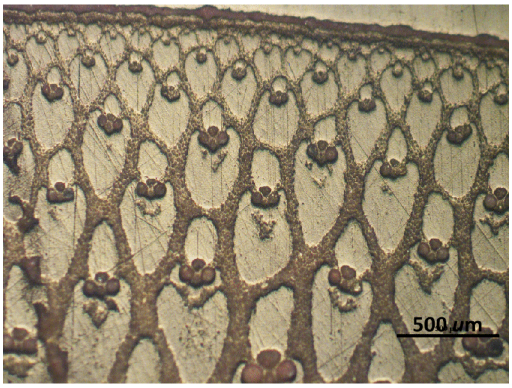

Figure 1. Vascular bundles of Tabah bamboo

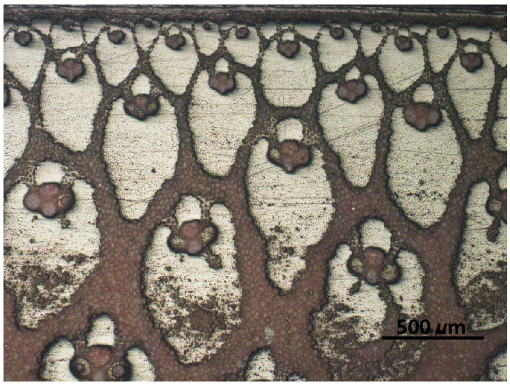

Figure 2. Vascular bundles of Tamblang bamboo

3.3. Vascular bundles and ultimate strength of tabah and tamblang bamboos

Table 3 shows the tensile and fracture strength of both bamboos. Tabah bamboo has higher ultimate and fracture strength than Tamblang bamboo. These higher values may related to their vascular bundles as shown in figures 1 and 2. Figure 1 and figure 2 illustrate the microstructure showing the vascular bundles in the cross section area of Tabah and Tamblang bamboos, respectively. There were differences in the vascular bundles between adjacent parts of the epidermis and part away from the epidermis. The vascular bundles adjacent parts of the epidermis have smaller size compared to the away from the epidermis and Tabah bamboo has higher bond density vascular bundles than Tamblang bamboo. This produced a higher tensile and fracture strength of Tabah bamboo compared to Tamblang bamboo, as shown in table 3. According to Sahu et al [3], raw material with higher ultimate strength has better potency to produce better quality of activated carbon.

4. Conclusion

Both Tabah and Tamblang bamboos were qualified as a raw material for activated carbon. However, Tabah bamboo will potentially produce better quality of activated carbon than Tamblang bamboo. It is due to its higher cellulose, carbon, and volatile contents, higher bond density vascular bundles and lower ash, silica and nitrogen contents. The next process is the selection of the appropriate carbonization and activation process parameters that can produce AC with high micro pores and surface area. So that it can be applied for ANG application. In addition, in terms of the availability, Tabah bamboo is obtained more easily compared to Tamblang Bamboo. Tabah bamboo is original species of Balinese bamboo and cultivated in almost all districts in Bali [29] while Tamblang bamboo mainly grow sporadically in Tamblang, Buleleng regency and also in Bangli regency, Bali, Indonesia. So that Tamblang bamboo is difficult to obtain in a large scale.

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