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Original article

Effect of Production Parameters on Electrical Properties of Woodceramics Made from Oil Palm Frond

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ABSTRACT

Woodceramics, a new kind of porous carbon material, has potential in many industrial applications, as it is environmental friendly and has a low production cost. In this research, woodceramics was prepared by carbonizing Medium Density Fiberboard (MDF), made from oil palm frond fiber impregnated with liquefied wood, converted from oil palm shell. Their ability to withstand maximum temperatures (600, 800, and 1,000 °C) and heating rates (1, 5, and 10 °C/min) during carbonization and changes in the physical and properties, as well as the electrical resistivity, were carefully investigated. The results indicate that during manufacturing, woodceramics lost a considerable amount of weight by about 60-65% and shrank in volume by around 45-62%. Physical properties, such as density, ranged between 0.6-0.85 g/cm^3 with moisture content roughly between 2.9-13%, while their ability to absorb water varied between 23-65%, depending on carbonizing conditions. Examined by ASTM D257 method, the electrical properties of the obtained woodceramics were affected by the levels of maximum temperature and heating rate. The results showed a decreasing trend in the electrical resistivity with increasing maximum temperature. Electrical resistivity rapidly decreased beyond a maximum temperature higher than 600°C and did not change at maximum temperatures close to 900°C. Moreover, a higher heating rate increased the electrical resistivity of woodceramics. The electrical resistivity of the woodceramics ranged between 5.16×102-6.4×109 Ω-cm, therefore nearly all woodceramics produced could be categorized as a semiconductor, especially for maximum temperatures ranging between 800-1,000°C.

Keywords: woodceramics, electrical properties, oil palm frond, liquefied wood, Medium Density Fiberboard.

INTRODUCTION

Woodceramics (WCMs) are a new kind of hybrid carbonaceous material with excellent operational properties. These are generally prepared from lingo-cellulosic materials by impregnated them with a thermosetting resin or liquefied wood and then sintered at high temperatures under air-tight conditions (Hirose *et al.*, 2002a; Oh, 2013; Qian *et al.*, 2004). WCMs are porous biomaterials consisting of amorphous and glassy carbon developed during thermoforming of carbonization process at temperatures between 300-2,800°C. With superior properties such as high porosity, lightweight, low friction, better wear and heat resistance, small thermal expansion, good chemical stability, electrical resistance, and electromagnetic shielding, WCMs have potential applications in heaters, gas filters, absorbents, humidity and temperature sensors, catalyst carrier materials, self-lubrication materials, heat insulating materials, damping materials, electromagnetic shielding, light structure ceramics, etc. (Kasai *et al.*, 1997; Shibata *et al.*, 1997; Akagaki *et al.*, 1999; Suda and Kakishita, 1999; Fujino *et al.*, 2002; Xie *et al.*, 2002; Zhang *et al.*, 2002; Huang *et al.*, 2012)

The residues from oil palm plantation, oil palm frond, and oil palm shell have been chosen in this research as a large amount of these aere left over or barely utilized (Prasertsan and Sajjakulnukit, 2006), providing a vast source of raw material in WCMs production. In 2015, Thailand's oil palm plantation covered an area of 4.7 million rais (0.752 million hectare) with an output of 11.01 million tonnes of oil. Their average growth rate ranges between of 5% to 7% per annum, in the last ten years, as a result of low cultivation costs and ease of maintenance in addition to a high yield,. Thailand ranks third in terms of plantation area and output (Wareerat, 2017) amongst all the countries. A byproduct of palm oil production, its residues have been identified as one of the most interesting biomass feedstocks for the bio-based economy in Thailand. According to estimates based on Laemsak (1996); Prasertsan and Sajjakulnukit (2006) method, oil palm fronds left in the field amounted to around 2.7 million tonnes (dry mass) per annum across the country (with an year round availability. The palm shells, obtained as byproduct of oil extraction process , find use as a boiler fuel in brick factories, as they are easily available at a reasonable cost and are an energy efficient source. However, application in other sectors still needs a lot of research.

The aims of this work are to produce WCMs from oil palm frond fiber by using liquefied wood, semi eco-adhesives, converted from both oil palm shells and ordinary phenol-formaldehyde (PF). Under different sintering conditions, following an experimental design, the changes in physical properties (water absorption, moistures content, weight loss, volume shrinkage, and bulk density) and electromagnetic shielding property were carefully studied.. Production of an environmentally friendly composite material such as the WCMs should also help in providing an alternative to the disposal of such agricultural waste and in turn help in reducing global warming.

MATERIALS AND METHODS

Materials

Oil palm fronds (OPFs) for this research were collected from the Nongsuea District, Pathum Thani Province, central Thailand. They were chipped and sieved, then dried at room temperature until the moisture content reduced below 10%. Next, the chips were cooked to separate the fiber by using steam refiner. The processed fiber was screened, dried, and stored in sealed containers. The oil palm shells, gathered from the Suksomboon Vegetable Oil Co., LTD., Chon Buri, eastern Thailand were ground and were dried under room temperature, similar to OPFs.

Methods

Material Preparation

Presently, there are two methods for making WCMs. In the first method, bulk wood or medium density fiberboard (MDF) is impregnated with PF resin or liquefied wood through selected techniques and then sintered at high temperatures. The second method involves the mixing of wood powder, such as sawdust or wood particles, with PF resin to produce a particleboard. Next, this particleboard is permeated with PF resin or liquefied and transformed to WCMs in the same way as in the first method. In this study, the prepared MDF was formed by mixing oil palm frond fiber, obtained from thermo-mechanical pulping process, with PF resin, which acts as an adhesive, in a 2:1 ratio by weight. Subsequently, the mixture was carefully poured into a molding box and a hot press was used to apply a pressure of 5 MPa, maximum temperature of 160 °C, for a duration of 10 min (Figure 1)

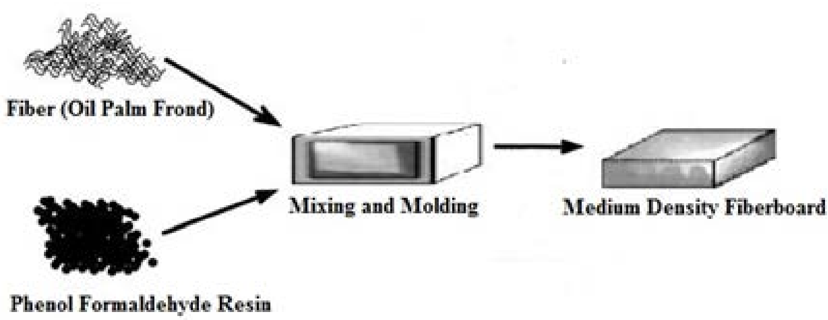

Figure 1 MDF Manufacturing Method.

In order to develop an eco-friendly material, in this research, WCMs were prepared from liquefied wood resin. To produce this resin, dry palm shell powder was allowed to pass through a screen of 100 meshes and was blended slowly with phenolic compounds in a ratio of 1:3 by weight, in three 2,000 mL round neck bottom flasks (Figure 2). The mixture was stirred at a speed of 1,000 rpm for 3 hrs at a reaction temperature of 150 °C by using 98% sulfuric acid as a catalyst. The maceration of oil palm shell to liquefied wood resin was complete when the mixture turned into a homogenous black colored liquid. The mixture was allowed to cool down at room temperature and diluted with ethanol in a ratio of 1:1 by weight, to reduce its viscosity before use.

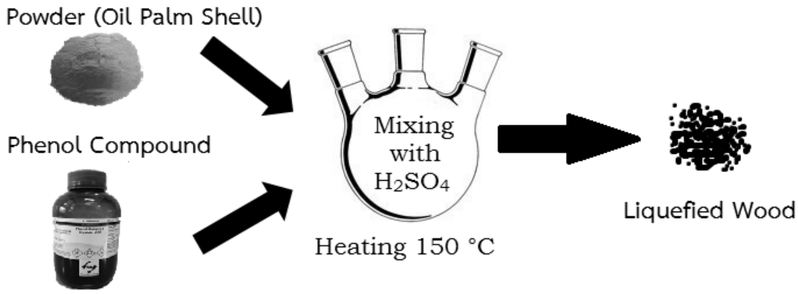

Figure 2 Liquefied wood preparation from palm oil shell.

After the MDF formation and liquefied wood preparation, as a next step, the MDF was impregnated with liquefied wood resin using a well-known wood preservation technique called the full-cell (Bethel) process, by applying pressure to push the preservative chemicals into the wood, providing an effective long-term resistance from fungi, bacteria, insects, and marine borers. The full-cell process involves the following steps: 1) the charge of wood was sealed in a treating cylinder and an initial vacuum (630-750 mmHg) was applied for around two hrs to remove as much air as possible from the wood and from the cylinder; 2) liquefied wood was introduced into the cylinder without breaking the vacuum; 3) the cylinder was pressurized until it reached a pressure of 10 MPa with a retention time of 4 hrs in order to obtain a better liquefied wood retention; 4) At the end of pressure period, the pressure was released and liquefied wood was removed from the cylinder, and 5) A final vacuum (630-750 mmHg) was applied to remove excess liquefied wood that would otherwise drip from the MDF.

Finally, the impregnated MDFs were sintered in a high-temperature muffle furnace at different heating rates (1, 5, and 10 °C/min) and at temperatures ranging between ambient to the desired maximum temperature (600, 800, and 1,000 °C) and then cooled to ambient temperature inside the furnace. The chemical and structural changes occur during the sintering of fiberboard composites. As a result, frond fibers are transformed into amorphous carbon, whereas PF resin becomes a glassy carbon. The dimension, weight decrease rate, and electrical characteristics were dependant on the thermoforming conditions and were also examined. A schematic diagram of the fabrication process is shown in Figure 3. For all sintering conditions, three finished WCMs would be randomly selected to check for their properties.

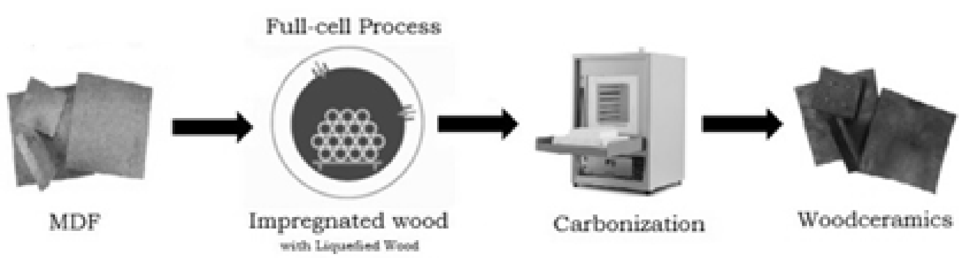

Figure 3 Schematic of the process for producing WCMs from Palm Oil Frond's MDF.

Experimental design

The experiment used a 3×3 complete randomized design with 3 replications. Finished WCMs were studied at three maximum temperatures (600, 800, and 1,000 °C) and three heating rates (1, 5, and 10 °C/min). Analysis of variance (ANOVA) and Duncan's Multiple Range Test were applied for data analysis, implemented in the R language, version 3.2.2 for Windows (R Development Core Team, 2011).

Characterization

The dimensions of each sintering conditions were measured using a digital slide caliper for both before and after carbonization. Similarly, weight changes were also measured using a digit electrical balance. Weight loss (Weight decrease rate) and volume shrinkage was calculated using the formula below.

$$\text{Weight loss (\%)} = \frac{(X_{BF} - X_{AF})}{X_{BF}} \times 100,$$

$$\text{Volume shrinkage (\%)} = \frac{(X_{BF} - X_{AF})}{X_{BF}} \times 100,$$

where X_{BF} is the weight (g) or volume (cm^3) before carbonization and X_{AF} is the weight (g) or volume (cm^3) after carbonization.

Other physical properties, such as moisture content, water absorption, and bulk density were computed from following formulas.

$$\text{Moisture content (\%)} = \frac{(M_1 - M_0)}{M_0} \times 100,$$

$$\text{Water absorption (\%)} = \frac{(M_2 - M1)}{M_1} \times 100,$$

$$\text{Bulk Density (g/cm}^3\text{)} = M_0 / V,$$

where M_0 is the oven dry mass (g), M_1 is the after conditioning mass (g), M_2 is the standardized soaked mass (g), and V is the after conditioning volume (cm^3), respectively.

Lastly, the electrical property of WCMs was examined following American Society for Testing and Materials (ASTM), 1994, D257 (ASTM D-257), by using the Resistivity Chamber instrument (Keithley Model 6150). This apparatus can measure resistance or conductance of insulating materials in terms of volume resistivity (ρ) with the following relationship between the independent variables:

$$\text{Volume resistivity, } \rho\ (\Omega\text{-cm}) = \frac{A*V}{I*t},$$

where A = cross-sectional area (cm^2), V = voltage (Volt), I = electrical current (Amperes), and

t = sample thickness (cm), respectively.

RESULTS AND DISCUSSION

Production of WCMs

For fiber preparation, palm frond chips were fed into Asplund defibrator under a steam pressure of 6.5 bars with a preheating or cooking time of 5 mins and defibrating time of 2 mins. Average pulp yield was about 52.68% (dry mass). For liquefied wood, after dilution with ethanol, the measured viscosity ranged between 1,890-1900 cP. After impregnation of liquefied wood in to the MDF by using full-cell process, the average sample weight increased by about 17.01%, while the average bulk density also increased by 14.21%. Conversely, the average moisture content decreased by about 47.65%. These effects resulted from the liquefied wood penetrating into the inner voids of the MDF samples.

Physical Properties

From information analysis (Figure 4), the WCMs lost a noticeable amount of weight ranging between 60-65%. This decrease was a result of an increase in the sintering temperature, in conformity with the works of Hirose *et al.* (2001, 2002b). However, the results for volume shrinkage indicated that it occurred under the effect of both maximum sintering temperature and heating rate. From Figure 4 it can be deduced that higher the sintering temperature, the more the volume of WCMs shrunk. Conversely, the higher was the applied heating rate, the lesser the volume of WCMs shrunk. The shrunk volume was around quantified between 45-62%. Results also indicated that the bulk density was the lowest at a sintering temperature of 600°C, but remained constant beyond a sintering temperature of 800°C. The heating rate also influenced the bulk density and from statistical analysis, it was found that a higher heating rate could decrease the bulk density of WCMs.

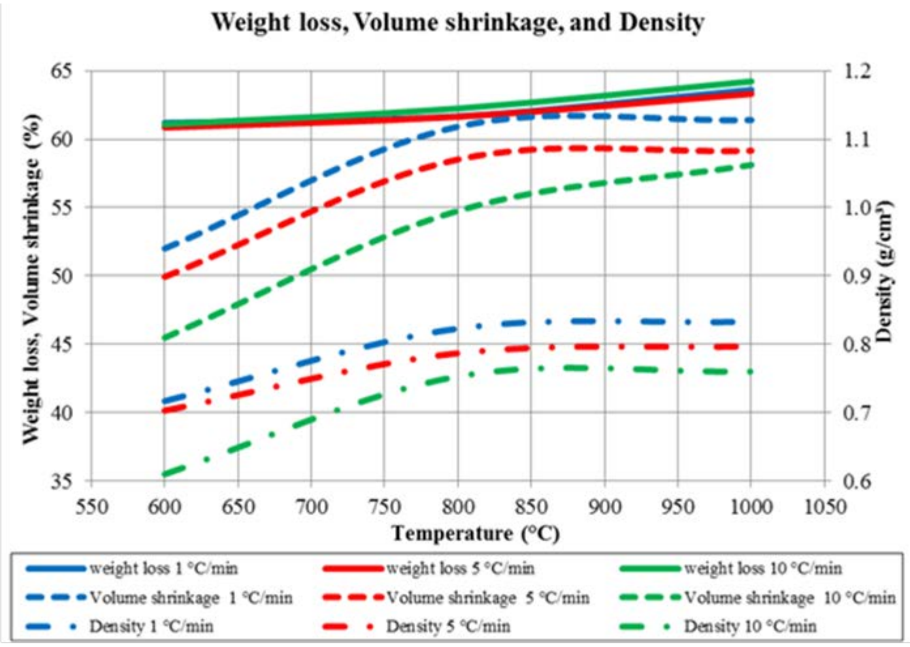

Figure 4 The changes in weight loss, volume shrinkage, and bulk density of WCMs from various sintering conditions.

The moisture content and water absorptionare properties important in various applications of WCMs. It was found that both maximum sintering temperature and heating rate effected both the moisture content (Figure 5) and water absorption (Figure 6) of WCMs. The higher the sintering variables, the greater the moisture content, but the expected levels of water absorption were met. Finally, for WCMs reported in this study, the density ranged between 0.6-0.85 g/cm^3, with a moisture content roughly between 2.9-13%, and their water absorption varied between 23-65%, depending on carbonizing conditions.

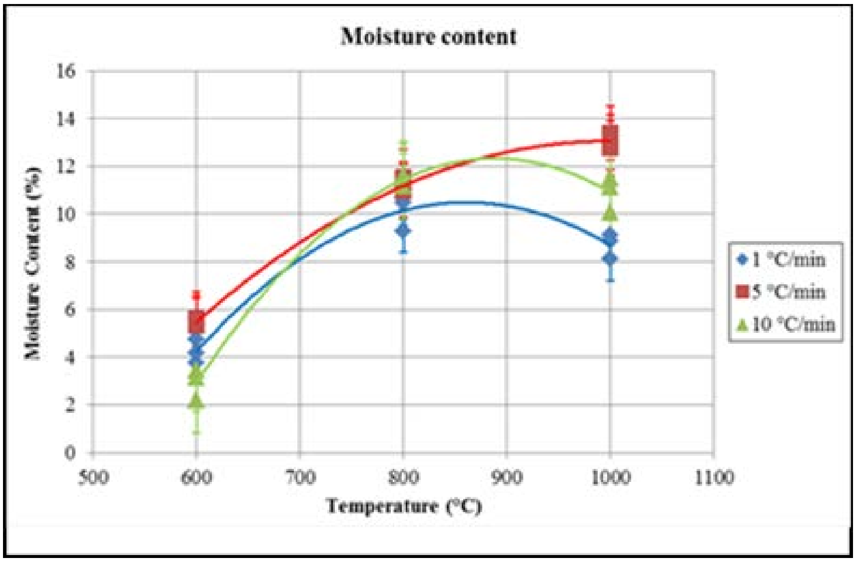

Figure 5 The percentage change inmoisture content of WCMs with varying temperature.

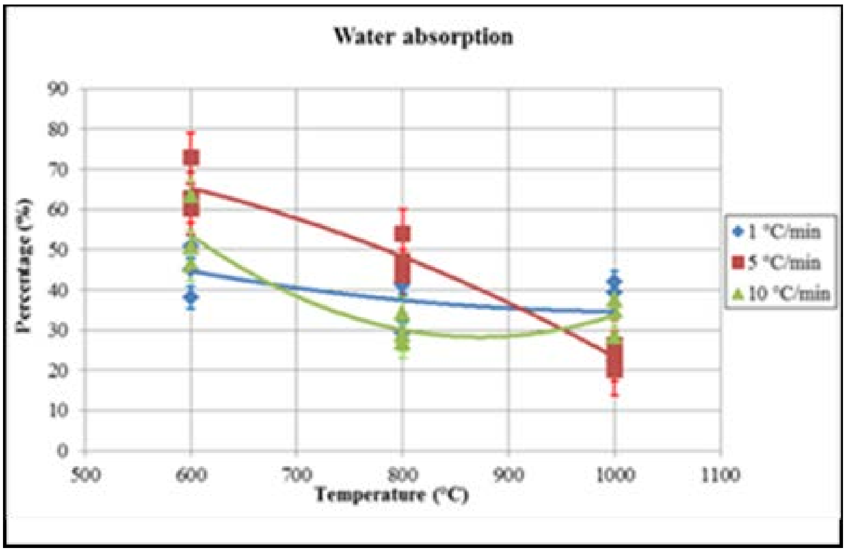

Figure 6 The percentage change inwater absorption of WCMs with varying temperature.

Electrical Properties

Figure 7 shows the electromagnetic shielding properties of the WCMs made from MDF at various thermoforming temperatures. This property was affected by both maximum temperature and heating rate. The results show a decreasing trend of the electrical resistivity when the maximum temperature was increased. The electrical resistivity values rapidly decreased when the maximum temperature was higher than 600°C, and remained constant at maximum temperature close to 900°C. The influence of heating rate on the electrical resistivity indicated that resistivity increased with the application of a higher heating rate.

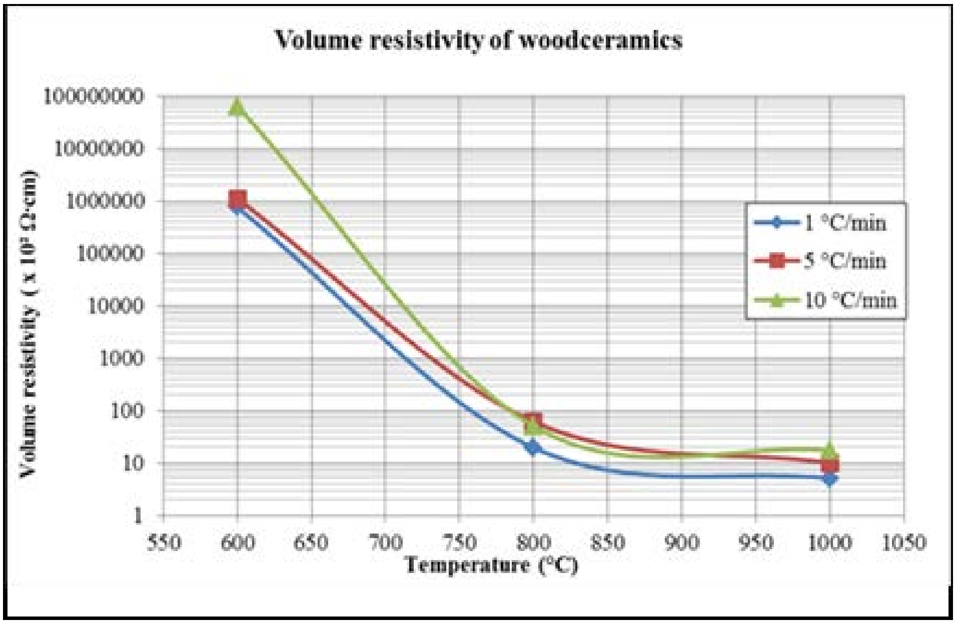

Figure 7 Effect of maximum. temp. andheating rate on volume resistivity of WCMs.

The electrical resistivity of the produced WCMs ranged between 5.16×10^{2}-6.4×10^{9} Ω-cm. Therefore, nearly all produced WCMs could be categorized as semiconductors, especially for maximum temperatures between 800-1,000 °C of sintering conditions.

CONCLUSION

To produce a more eco-friendly WCMs, in this study, the MDF from palm fronds fiber was impregnated with liquefied wood converted from oil palm shell and PF resin, using the Asplund process. The effects of both maximum temperature and heating rate during carbonization on the physical properties and electrical resistivity of WCMs was investigated. From the statistical analysis, the following conclusions can be drawn:

1. Only the maximum sintering temperature had an effect on weight loss of the produced WCMs.

2. The higher the maximum sintering temperature and the lower the heating rate, the higher the volume shrinkage and bulk density of WCMs was.

3. The higher the assigned sintering variables, the higher was the moisture content, but the lower was the water absorption. This could be due to pore structural changes during thermal decomposition of WCMs

4. The measurement results showed that the electrical resistivity of produced WCMs ranged between 5.16×102-6.4×109 Ω-cm, and as such, nearly all produced WCMs were semiconductors, especially at maximum temperature between 800-1,000°C.

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