Analysis of the Calcination Temperature Variations Effect on the Physical Properties of Silica Extracted from Bamboo (*Dendrocalamus asper*) Leaves

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Abstract. Silica (SiO_2), an inorganic material with a unique structure, finds extensive application in catalysis, adsorbent materials, and electronics due to its physical properties. This study investigates silica extraction from bamboo leaves (*Dendrocalamus asper*), an underutilized agricultural waste, offering an environmentally friendly and sustainable alternative to conventional silica sources. The extraction process includes ashing at 600°C, acid leaching with 5M HCl, and calcination at varying temperatures (700°C, 800°C, 900°C, and 1000°C). The calcined silica was characterized for electrical and thermal conductivity. Results revealed that higher calcination temperatures enhance both electrical and thermal conductivity, attributed to increased crystallinity and reduced porosity, facilitating charge and heat transport. The study underscores the potential of bamboo leaf silica for advanced applications, particularly in semiconductor and thermal energy storage materials, and highlights the critical role of calcination temperature in tailoring silica properties to specific industrial needs.

Keywords: Silica, Calcination Temperature, Electrical Conductivity, Thermal Conductivity.

1 Introduction

Silica (SiO_2) is an inorganic material with a unique structure, enabling its widespread application in various fields, including catalysis, adsorbent materials, and electronic devices [1, 2]. The production of silica can be achieved either through chemical synthesis or extraction from natural sources. The extraction of silica from natural materials such as sand and agricultural waste has garnered attention as an environmentally friendly method, particularly for utilizing abundant yet underutilized waste. One promising agricultural waste is bamboo leaves, especially from the species *Dendrocalamus asper*, a member of the Gramineae family, which is rich in silica content [3].

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Bamboo leaves are often regarded as waste, despite their high silica content, which can exceed 70% [4, 5]. The extraction process from bamboo leaves involves leaching using acids and subsequent calcination to enhance the purity and physical properties of silica. Utilizing this waste not only reduces environmental impact but also provides a sustainable and cost-effective alternative source of silica. This advantage positions bamboo leaf silica extraction as a vital strategy for agricultural waste management and supporting the development of a circular economy [6].

Silica exhibits significant electrical and thermal conductivity, depending on its structure and purity. Its electrical conductivity plays a crucial role in the electronics industry, while its thermal conductivity is utilized in thermal insulation materials and energy applications. Research on how calcination temperature variations influence these physical properties is essential to optimize silica for specific applications. A comprehensive understanding of the relationship between calcination temperature and conductivity properties can facilitate the development of advanced silica-based materials [7, 8].

The leaching process employs strong acids, such as HCl, to dissolve organic components and other minerals, leaving behind pure silica in the ash of bamboo leaves [9, 10]. Following leaching, the calcination stage involves heating the samples at various temperatures (700–1000°C) to improve the structure and physical properties of silica. Calcination temperature is known to influence silica's morphology, pore size, and chemical bonds, which in turn affect its electrical and thermal conductivity [5, 11]. This study's focus on calcination temperature variations aims to provide detailed insights into the changes in silica properties, enabling its optimization for specific applications.

2 Methods

Silica can be extracted from organic natural materials such as bamboo leaves. In this study, the materials used were petung bamboo (*Dendrocalamus asper*) leaf waste, 5M HCl solution, 70% alcohol, and distilled water. The tools used include a 100 mesh sieve, hot plate and magnetic stirrer used in the leaching process, whattman 41 filter paper, a furnace for the process of ignition and calcination, and pellet pressure to form powder samples into pellets before being characterized. The tools used in the characterization process are divided into two groups. For electrical conductivity characterization, the tools used are power supply, ammeter, voltmeter, connecting cables, and jumper cables. As for the characterization of thermal conductivity, the tools used are thermoline, iron samples, and infrared thermometers.

The stages of the research carried out were preparation of raw materials, ashing of bamboo leaves, leaching, calcination, and characterization. Preparation of raw materials was carried out by washing, drying, and cutting bamboo leaf waste samples. After that, the bamboo leaf waste that had been cut into pieces was put into a furnace at a temperature of 600°C for 4 hours for the ashing process. The bamboo leaf ash was then ground and sieved with a size of 100 mesh. The next process is the leaching process which is carried out by mixing 20 grams of bamboo leaf ash with 240 ml of 5M HCl. The mixture was then stirred in a magnetic stirrer at a temperature of 110°C at a speed of 240 rpm for 3 hours. After that, the sediment and filtrate were separated with Whattman 41 filter paper. The sediment was then dried in an oven at a temperature of 110°C for 2 hours. After the leaching process is complete, the next stage is the calcination process which is carried out using a furnace for 2 hours with temperature variations of 700°C, 800°C, 900°C, and 1000°C. The selection of the calcination temperature within this range is based on the fact that at these temperatures, complete decomposition of organic compounds and the formation of a more organized silica structure occur. Calcination within this temperature range produces silica with a more defined and homogeneous structure, indicating an improvement in the quality of the resulting silica [12, 13].

The calcined samples are then formed into pellets using a pellet pressure of 50 kg/cm2. For the characterization of electrical conductivity, the samples are installed in an electrical circuit as shown in Figure 1 while for the characterization of thermal conductivity, the samples are arranged on a thermoline as shown in Figure 2.

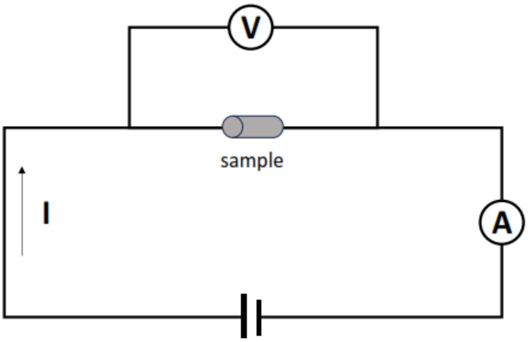

Fig. 1. Electrical circuit for electrical conductivity characterization

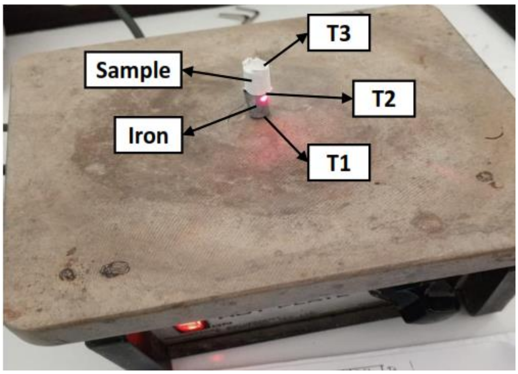

Fig. 2. The configuration of thermal conductivity characterization using thermoline

In the characterization of electrical conductivity, the voltage and current are measured and then the data is plotted on the I vs V graph. The electrical resistance value R of each sample is the reciprocal of the gradient of the I vs V graph. Furthermore, the resistivity and electrical conductivity are calculated using equations 1 and 2.

$$\rho = RA/L \tag{1}$$

$$\sigma = 1/\rho \tag{2}$$

where ρ is the electrical resistivity (Ω.m), σ is the electrical conductivity (S/m), R is the electrical resistance (Ω), A is the cross-sectional area of the sample (1.25×10^{-3} m^2), and L is the length of the sample (1×10^{-2} m).

The thermal conductivity value of silica extracted from bamboo leaves was calculated using the Fourier law comparison of thermal conductivity. The equation uses iron as a comparator and is mathematically expressed by equation 3.

$$q_{iron} = q_{sample}$$

$$\kappa_{iron} \times A_{iron} \times \frac{\Delta T_{iron}}{\Delta l_{iron}} = \kappa_{sample} \times A_{sample} \times \frac{\Delta T_{sample}}{\Delta l_{sample}} \tag{3}$$

where q_{iron} is the iron heat transfer rate (W), q_{sample} is the sample heat transfer rate (W), κ_{iron} is the iron thermal conductivity (73 W/mK), κ_{sample} is the sample thermal conductivity (W/mK), A_{iron} is the iron cross-sectional area (5.024×10^{-3}m2), A_{sample} is the sample cross-sectional area (5.024×10^{-3}m2), ΔT_{iron} is the temperature difference between iron and the intermediate plane (K), ΔT_{sample} is the temperature difference between sample and the intermediate plane (K), Δl_{iron} is the iron length (2×10^{-2} m), and Δl_{sample} is the sample length (2×10^{-2} m).

3 Results and Discussion

The treatment for characterization of electrical conductivity was carried out by changing the calcined powder sample into a solid using pellet pressure. The surface of the sample was given a copper plate and mounted on a circuit as shown in Figure 1. The circuit was then connected to a voltage source so that electricity could flow. The circuit was also connected to a voltmeter and ammeter to measure the voltage at the ends of the sample and the current flowing through the sample. The results of the voltage and electric current measurements are presented in Table 1. The values of voltage V and current I are then plotted on the I vs V graph shown in figure 3.

Table 1. Results of voltage and electric current measurements on samples

Voltage V_s (Volt)	Electric Current I (μA)			
	700℃	800℃	900℃	1000℃
0,5	1	2	2	1,8
1	2,2	3,2	4	5
1,5	4	5	6,2	7,2
2	6,4	8	9	9,4
2,5	8,2	10	11,8	12,8
3	10	13,2	14	15
3,5	14,2	18,6	18	19
4	19	20	21,2	22,4
4,5	21	22,2	25	25,8
5	25,2	26	28,6	29
5,5	28	29	30	31,6
6	31	32	33	34

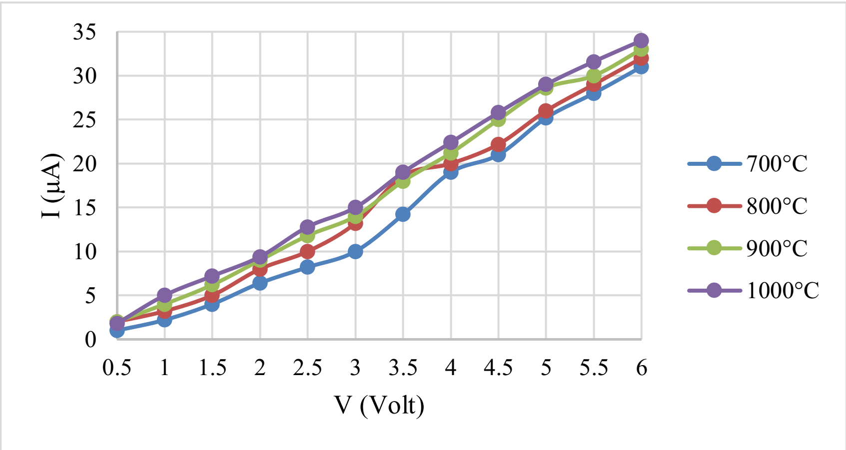

Fig. 3. I vs V graph of each sample

The gradient of the graph and the resistance R of the sample are reciprocal. Based on the results of the graphic analysis, the resistance value of each sample was obtained and presented in table 2. After that, the data was processed using equations 1 and 2 to obtain the electrical resistivity and electrical conductivity values which also presented in table 2.

Table 2. Electrical resistance, electrical resistivity, and electrical conductivity values of silica samples extracted from bamboo leaves at various calcination temperatures

Calcination Temperature (℃)	Electrical Resistance (Ω)	Electrical Resistivity (Ω.m)	Electrical Conductivity (S/m)
700	2.14×10^5	2.68×10^4	3.73×10^{-5}

800	1.98×10^5	2.48×10^4	4.03×10^{-5}
900	1.87×10^5	2.33×10^4	4.28×10^{-5}
1000	1.79×10^5	2.24×10^4	4.47×10^{-5}

Furthermore, the treatment for thermal conductivity characterization was carried out by shaping the calcined powder sample into pellets with pellet pressure. The sample was then attached to the thermoline with a configuration as shown in Figure 2. After the thermoline was heated for 5 minutes, the temperature at the tip of the sample, the sample interface with the iron, and the tip of the iron in contact with the thermoline was measured. Measurements for each sample were carried out 3 times and the final result used was the average of the three measurements. After that, the data was then calculated using equation 3 to obtain the thermal conductivity value of the silica sample. The results of the measurements and calculations are presented in Table 3.

Table 3. The relation of calcination temperature and temperature measurement as well as thermal conductivity of silica samples extracted from bamboo leaves.

Calcination Temperature (°C)	Temperature Measurement Results on Sample Heating with Thermoline			Thermal Conductivity (W/mK)
	T_1 (K)	T_2 (K)	T_3 (K)	
700	409,15	406,48	401,42	38,52
800	415,78	410,38	405,98	89,59
900	412,22	407,75	404,65	105,26
1000	410,45	405,72	404,52	287,74

The results showed that increasing the calcination temperature from 700°C to 1000°C increased the electrical conductivity of silica extracted from bamboo leaf ash. This phenomenon can be scientifically explained by changes in the structure of the material at high temperatures. As the calcination temperature increases, the crystallinity of silica tends to increase, and there is a possibility of the formation of crystal phases such as cristobalite or quartz at high temperatures [12]. This structure affects the electronic properties of the material, such as the density and mobility of charge carriers. In addition, high temperatures reduce porosity and increase the density of the material, thereby facilitating the transport of electric charges through more connected pathways [14].

The results of the characterization of thermal conductivity show that its value continues to increase with increasing calcination temperature. At higher calcination temperatures, the amorphous structure of silica tends to change into a more crystalline structure. Higher crystallinity increases the order in the atomic network, which facilitates the propagation of phonons, which are the main carriers of heat in non-metallic materials such as silica. Thus, the higher the crystallinity, the lower the resistance to heat flow, thereby increasing thermal conductivity. Higher calcination temperatures also reduce the porosity of the material. Pores trap air, which is a thermal insulator. As porosity decreases, the density of the material increases, allowing phonons to move more efficiently through the material without much scattering or resistance at the pore surface [15, 16].

Knowledge of the physical properties of silica, especially its electrical and thermal properties, is very useful in the utilization of silica in various fields. Although pure silica is generally an electrical insulator, this property can also be modified to meet specific needs. In the electrical component industry, silica is widely used as a base material for semiconductor components [2, 7]. In addition, knowledge of the thermal properties of silica is also useful because silica is widely used as a thermal energy storage material and silica aerogel [8, 17]. Although in the mentioned application silica with low thermal conductivity is used, this study shows how to prepare the silica to be used according to its needs.

4 Conclusion

The conclusion that can be drawn from this study is that the calcination temperature affects the physical properties of silica, especially its electrical conductivity (electrical properties) and thermal conductivity (thermal properties). From the results of the data analysis, it is known that the higher the calcination temperature, the electrical conductivity and thermal conductivity of silica also increase. This is because the increase in temperature in the calcination process can increase the crystallinity of silica.

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