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Characterization of Rice Husk Silica Foam Fabricated by Slurry Method for Water Filter Application

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Abstract

Rice husk, a byproduct of rice milling composed of cellulose, hemicellulose, lignin, silica and ash. This study investigates the characteristics of silica from rice husk processed via the slurry method for water filter application. This research aims to produce silica using rice husk with a slurry method, analyse the physical properties and examine the surface structure of silica after sintering process and compare the properties between rice husk from Pasir Tumboh and Pasir Puteh. The rice husk is gathered, cleaned, and combined with other ingredients to form a slurry, which is then applied to a substrate. The properties of silica such as density and porosity, are influenced by the composition of material in slurry. This research focuses on silica production for water filter application by using a combination of silica, distilled water and Polyvinyl Alcohol (PVA) as a binder agent, with the composition of silica set at 45 wt.%, 50 wt.% and 55 wt.%. The filters are evaluated through physical tests, including density and porosity. Surface morphology is analysed using Scanning Electron Microscopy (SEM). The results state that 45 wt.% silica from Pasir Tumboh produces a sample with a porosity of 76.58% and density of 0.52 g/cm^3. While Pasir Puteh created a sample with a porosity of 86.40% and density of 0.30 g/cm^3. Hence, it is shows that silica from Pasir Puteh produce the best result for water filter application as a higher porosity water filter could improve water flow rate and reduce the clogging while lowest density would increase the surface area and effective in water filtration.

1. Introduction

The issues of water shortage and demand for clean water led to the fabrication of water filtration systems. In this research, the aim is to produce a water filter by using silica which derived from the agricultural residue rice husk and has a distinct quality for water filtration applications [1]. The rice grain's outer layer, known as "husk" or "hull", consists of 20% weight of rough rice and the byproduct of rice milling. Utilizing RH can help in reducing waste and promote the development of sustainable products [2] and aims to develop an efficient and affordable water treatment solution [3]. Before this, most water filters were produced by using porous ceramic membranes. However, the high cost of pure ceramic powders and the necessity for high sintering temperatures significantly increase the manufacturing cost. Hence, by using rice husk as a source of silica for raw materials, a more economical alternative has been introduced to the engineers [4]. A porous structure of silica foam helps in trapping the impurities as water flows through it.

Rice husk is composed of 36% - 40% cellulose, 12% - 19% hemicellulose, and 17% - 19% lignin. Its complex crystal structure and the tight binding of hemicellulose and cellulose microfibrils hinder the effectiveness of cellulose hydrolysis. Therefore, effectively releasing and breaking down the cellulose is important to utilizing the biomass from rice husk [5]. Commonly, the collected rice husk will be cleaned to remove foreign elements and dried under sunlight for three days. Then, the dried husk will be ground using an electrical horizontal roller mill to reduce its size and texture. After that, samples were extracted from pre-calcinated material obtained by heat-treating the pre-washed, dried and powdered rice husk to 350^{0}C. These rice husks were further heated to 450 ^{0}C, 550 ^{0}C and 650 ^{0}C, then subjected to physiochemical analysis [6].

Silica serves multiple roles in water treatment such as pH adjustment to neutralize acidic or basic conditions [7], use in the desalination process to be addressing structural integrity issues by incorporating non-covalently bound organic templates to prevent microspore collapse [8] and lastly, affect the efficiency of Reverse Osmosis (RO) membranes leading to scaling on the membrane surface [9].

A slurry consists of liquid and solid components, typically water as the liquid phase. The solid particles in a slurry can vary in size from microscopic to several millimeters. Slurries find applications in various fields such as solid transportation, mineral separation, drilling and construction. Examples of slurry methods include slurry displacement piles used in construction, slurry shield technique in tunneling projects and process for dewatering slurry to separate solids from liquids [10].

2. Materials and Methods

The details of material and fabrication are explained in this part, which lists the materials and procedure of the slurry method. Additionally, the physical test and Scanning Electron Microscopy (SEM) would also be described.

2.1 Raw Materials

Six samples of silica for water filter application would be produced using the slurry method by mixing the silica, Polyvinyl Alcohol (PVA), and distilled water according to the composition. Table 1 shows the composition of silica for both Pasir Tumboh and Pasir Puteh, as well as the PVA and distilled water needed to make the slurry.

Table 1 *Composition of materials*

Type	Silica (wt.%)	PVA (wt.%)	Distilled Water (wt.%)
Pasir Tumboh	45	5	50
	50	5	45
	55	5	40
Pasir Puteh	45	5	50
	50	5	45
	55	5	40

2.2 Sample Preparation

There are several processes involved in slurry method to create a silica foam from rice husk-derived silica from Pasir Tumboh and Pasir Puteh, and the subsequent material testing. The fabrication of samples begins by mixing the Polyvinyl Alcohol (PVA) and distilled water until it turned to a PVA solution. Then, the PVA solution was combined with the silica from Pasir Tumboh according to the composition in Table 1. Once, the slurry is achieved, the 7 cm PU foam would be soaked in the slurry mixture and proceed to run a dipping and pressing process. The dipping and pressing process needs to be repeated according to the size of the PU foam to ensure the slurry is absorbed inside the PU foam. Then, it undergoes a drying process for 24 hours in 100^{0}C to remove the moisture and achieve the consolidation of the material. Lastly, the dried silica foam was sintered in the furnace for 1200^{0}C. Repeat each step by changing the silica to Pasir Puteh.

2.3 Surface Morphology

Silica foam would run a surface structure analysis by using SEM to identify the microstructure of the sample after going through a sintering process. The sample will be coated with gold first before scanned inside the SEM to improve the sample's conductivity, reducing charging that can affect and distort the image during analysis. The aim is to identify and measure the closed pore, open pore, strut and joint in the water filters.

2.4 Physical Testing

Each sample should be measured in percentage of porosity and density to assist in the analysis of physical properties. Initially, the sample would be weight in a dry condition before boiled in the hot water for 2 hours to remove any impurities in the silica water filter. Then, submerged the sample into distilled water in room temperature for 12 hours to remove any air pockets trapped within the sample. Ensure that the excessive water from the specimen is left dry after weighing the suspended weight using filter paper before weighing the wet weight. Equation 1 shows the formula for the percentage of porosity, while equation 2 displays the formula to calculate the density of the sample.

$$Percentage\ of\ porosity = \frac{W_{wet} - W_{dry}}{W_{wet} - W_{soaked}} \times D \times 100\% \quad (1)$$

$$Density = \frac{W_{dry}}{W_{wet} - W_{soaked}} \quad (2)$$

3. Results and Discussion

The result from this research consists of surface morphology and physical properties of different types of samples.

3.1 Surface Morphology

The images obtained from SEM show different results from different compositions of silica and different types of rice husk in terms of pore distribution and pore size. Fig. 1 displays the surface structure of silica from Pasir Puteh.

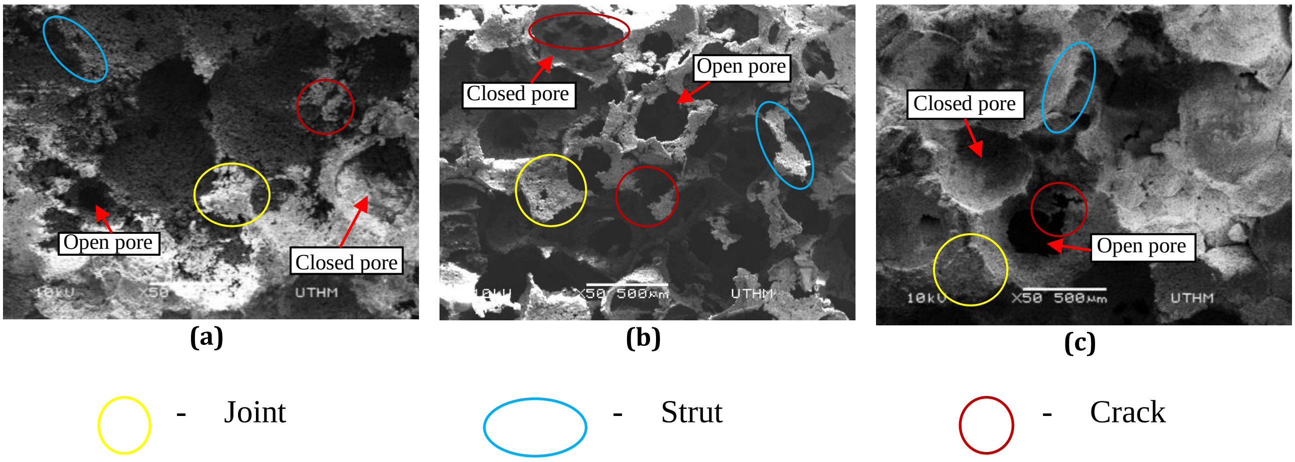

Fig. 1 *Surface morphology of foam with (a) 45 wt.%; (b) 50 wt.%; (c) 55 wt.% silica from Pasir Puteh*

Based on the microstructure analysis, all samples show porosity that varies by pore size, structure of open pore, closed pore, joint and cracks in the structure. The porosity of each sample is inversely proportional to the amount of silica used in slurry. As the silica increases, the porosity would be decreased because the pores in the foam are filled with silica, shrinking the size. The 45 wt.% silica foam from Pasir Puteh creates a water filter with the highest average pore size compared to other two. Theoretically, a 50 wt.% silica foam should have a higher average pore size compared to 55 wt.% silica foam. However, the outcome from this research is different as the average pore size from 55 wt.% silica foam is higher compared to 50 wt.% silica water filter. This is because, when the silica water filter does not adequately absorb the slurry undergo a sintering process, it will burn and form a crack in the structure as shown in Fig. 1(b). The burning causes the existing pores to break, resulting in fewer and smaller pores in the sample. Moreover, as the amount of silica increases, the foam should have less surface area to expand, which leads the pores to be smaller and form a closed pore such as displayed in Fig. 1(c), resulting in a denser structure of the sample. Table 2 lists the average pore size of the silica water filter from Pasir Puteh.

Table 2 *Average pore size in silica water filter from Pasir Puteh*

Silica (wt.%)	Average Pore Size (µm)
45	549.85
50	312.36
55	466.37

3.2 Physical Testing

Physical testing is an important step in material characterisation as it provides insights into their structural and functional properties. Density and porosity testing is one of the significant analyses of materials intended for filtration application. Density testing is used to understand the compactness and structural integrity of each specimen while porosity testing evaluates the void spaces within the material to influence its filtration efficiency. Table 3 lists the value of porosity and density for each sample. Fig. 2 illustrates the composition against the percentage of porosity, while Fig. 3 shows the composition against density for the silica water filter.

Table 3 *Value of density and porosity for each silica water filter specimen*

Type	Silica (wt.%)	Porosity (%)	Density (g/cm^3)
Pasir Tumboh	45	76.58	0.52
	50	75.54	0.55
	55	67.89	0.73
Pasir Puteh	45	86.40	0.30
	50	83.56	0.36
	55	79.14	0.50

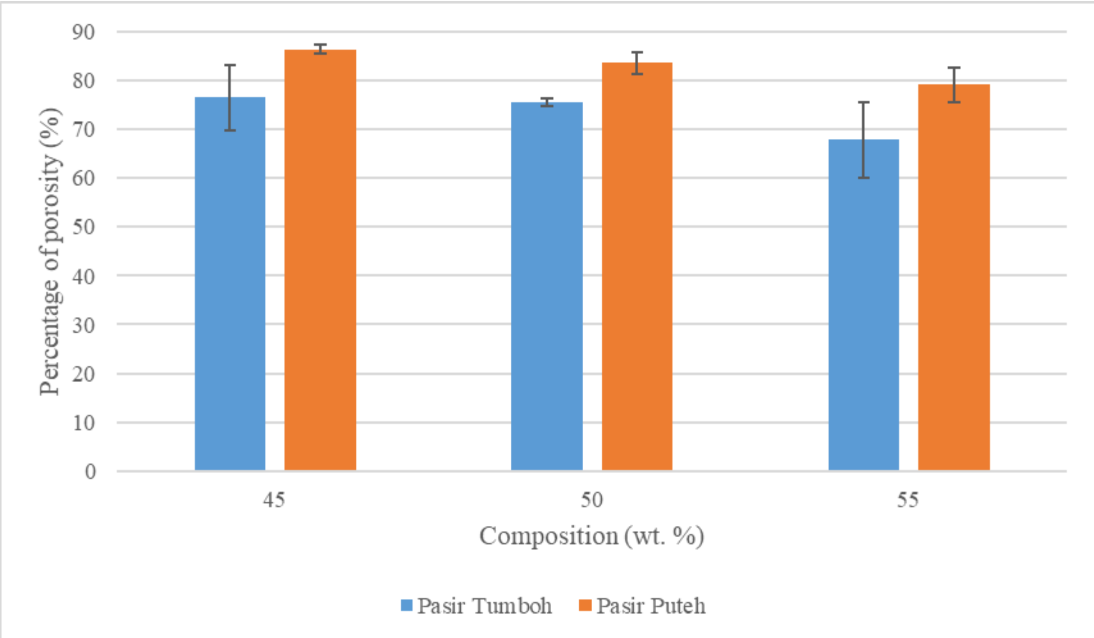

Fig. 2 *Percentage of porosity against different compositions of silica from Pasir Tumboh and Pasir Puteh*

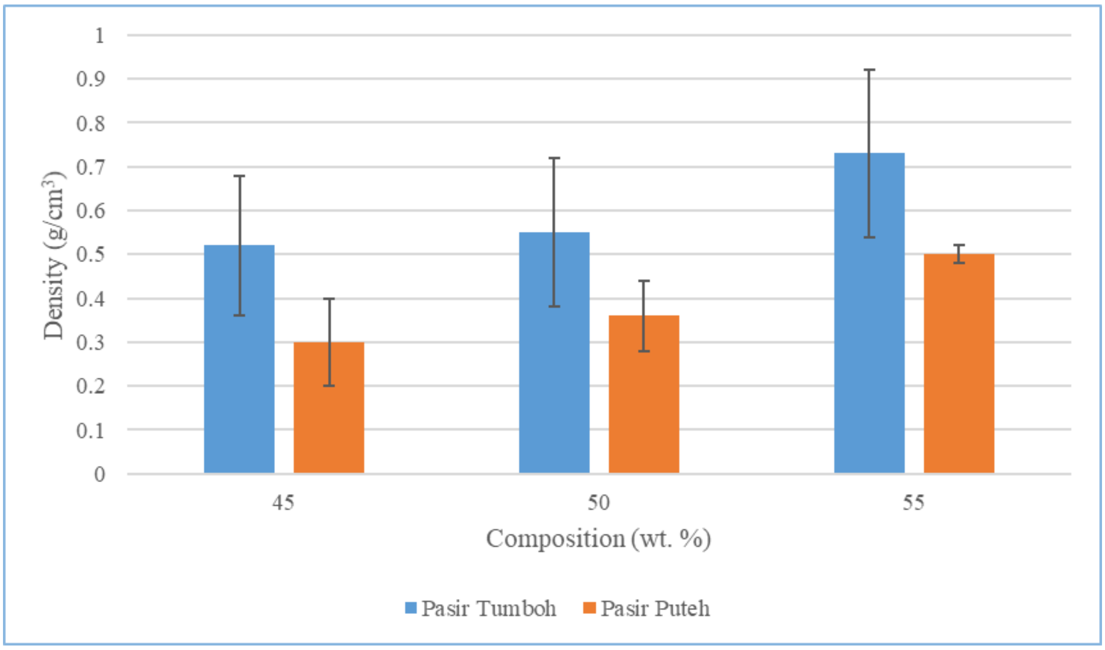

Fig. 3 *Density against different compositions from Pasir Tumboh and Pasir Puteh*

Fig. 2 displays the porosity results for each silica composition from Pasir Tumboh and Pasir Puteh. The composition of 45 wt.% produces the highest porosity in silica water filter, followed by 50 wt.% composition of silica from both areas. While 55 wt.% silica creates the lowest porosity of silica water filter. The graph of porosity against different compositions from Pasir Tumboh and Pasir Puteh are inversely proportional as the composition of silica used in slurry increases, the percentage of porosity will decrease.

Meanwhile, the data shown in Fig. 3 illustrate the graph of density against different composition according to Pasir Tumboh and Pasir Puteh. From the result, we could see that the highest composition of silica 55 wt.% creates a denser silica foam, follow with 50 wt.% that have a dense product and the composition of 45 wt.% silica from both areas produces a silica water filter with the lowest density. The data concludes that the relationship between density and silica composition are directly proportional as the higher the composition of silica used in slurry, the higher the density of the specimen.

This relationship between density and porosity in specimens is clearly illustrated in Fig. 1(c) where the porosity will decrease when the density increases. This is all due to the ability of particles to fill the pores within the PU foam, which is improving with the increase in the silica composition used during fabrication. Fig. 1(c) proves that a significant number of closed pores are produced in the sample. The silica effectively fills the pores, eventually leading to their closure.

Moreover, from both graphs, we can conclude that rice husk-derived silica from Pasir Puteh creates a more porous water filter compared to silica from Pasir Tumboh. From research, it is stated that the strength of crystalline silica powder from Pasir Tumboh is higher compared to Pasir Puteh because the uniformity of its elements and structure remains stable across different temperatures [11].

4. Conclusion

In conclusion, this study evaluated the effectiveness of rice husk-derived silica in fabricating water filters using the slurry method. Rice husk, an eco-friendly and renewable material, offers a sustainable resource. Results in physical testing show that the highest material content, 55 wt.% composition of silica in slurry lead to a denser, less porous water filters, while lower composition which is 45 wt.% of silica produces a higher porosity and lower density. Scanning Electron Microscopy (SEM) analysis confirmed these results by revealing the surface structure of each sample. Silica from Pasir Tumboh exhibited better structural integrity and pour filling, while silica from Pasir Puteh was more porous and structurally fragile. The research objectives were achieved through the successful fabrication and characterization of the samples. Thus, 45 wt.% of silica from Pasir Puteh produced the best silica foam despite its structural fragility, the larger and more unevenly distributed pores lead to higher porosity, making it more suitable for water filter applications.

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