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Recycling of Wood Saw Dust Waste as Green Pore Forming Agent for Porous Ceramic

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Abstract. Porous ceramic fabrication using natural pore forming agents have received more and more attention in the past few years. However, researchers have encountered an issue with an inconsistent particle size, which led to uneven pore distribution. Considering waste material as pore forming agent, this research seeks to explore the potential application of wood sawdust in porous ceramic production. Moreover, the effects of wood sawdust weight percentage (wt.%) and firing temperature towards the physical and mechanical properties of porous ceramic will also be investigated. Porous ceramic was fabricated by introducing two different proportions of wood sawdust (10 and 20 wt.%) into China clay, followed by drying at 110°C and firing at 900°C. The characterization analyses were performed by means of Fourier Transform Infrared spectroscopy, water absorption, apparent porosity, bulk density, and X-Ray Diffraction. The results showed that the compressive strength appears to decrease as the composition of the waste wood sawdust increases. Relatively, the water absorption value increases as the wood sawdust incorporation increased. This is because more porosity formation is observed at a higher sawdust ratio, leading to a lower density of the ceramic.

1. Introduction

Generally, porous ceramics are a class of highly reticulated ceramic material that can be observed in several types of pore structures such as micro- and meso- porous materials, foam-and honeycomb structures, as well as multilayer materials. Most importantly, their unique combination of valuable properties such as porosity, water absorption and modulus of rupture (MOR), contributing to its usefulness in a variety of conventional and advanced engineering applications. Simply put, it possesses low density despite high mechanical and physical strength, low thermal conductivity with a high melting point in addition with good corrosion resistance [1].

Pore forming agents can be separated into two parts, namely renewable resources and mineral resources [2]. Natural pore forming agent such as wheat straw, rice husk ash, and many more are very well-known for the porous ceramic fabrication for their economic value and non-toxicity. However, it is rather challenging to simultaneously control the porosity and mechanical properties of the ceramic due to the inconsistent particle size and morphology of the natural agent. Although this may be true, wood sawdust can possibly be used as pore forming agents because of the fine and uniform particle size distribution, ranging from 1.5 µm to 63 µm [3]. It has a low ignition point of approximately 118°C to 142°C allowing pore formation at much lower heat during firing [4]. This will subsequently be capable of reducing embodied energy as well as carbon footprint for the porous ceramic production. Moreover, the formation and size distribution of porosity can be easily controlled by altering the starting size of sawdust.

Despite this interest, no one to the best of our knowledge has studied the by-product of natural residue as pore forming agent to create a porous ceramic. Therefore, this study aims to draw attention to the potential utilization of wood sawdust as pore forming agent in porous ceramic as well as to investigate the effects of wood sawdust content (wt.%) and firing temperature to physical and mechanical properties of porous ceramic.

2. Methodology

2.1. Materials
Wood sawdust (WSD) was obtained from TS Timber Industries (Jeli) Sdn Bhd, while China clay was supplied by Kaolin (Malaysia) Sdn Bhd.

2.2. Method
First, WSD was dried at 110ºC for 24 hr and ground into a fine powder using a high-speed mill for 15 min. Afterward, the dust powder was sieved to a particle size below 300 µm. Next, the fine powder of WSD was subjected to FTIR spectroscopy to determine the functional groups which present in it. Later, it was mixed with china clay with 300 ml water in a mixer for 1 hour, followed by drying for 24 hr at 110°C. Next, the dried mixture was milled by using a mortar to produce powder mixture and re-homogenize components in the mixture as there is a tendency for high-density component to form sediment during the slurry's drying process. Subsequently, the granulation process was performed on powder mixture by introducing approximately 5 to 6 wt. % (2.5 to 3.0 g) of distilled water per powder mixture (50 g). Next, the granule powder was compacted by applying 40 MPa pressure using the uniaxial hydraulic press, producing a green body of 40 mm diameter. The green body was dried for 24 hr at 110°C in an electric oven prior to firing in a muffle furnace for 1 hr. Lastly, the naturally cooled porous ceramic were characterized accordingly.

Water absorption, apparent porosity as well as bulk density characterizations were conducted in accordance with MS ISO 10545-3: 1995 standard. After that, the sample was subjected to a compressive test using a universal testing machine. The sample was crushed fully under the compression test, and Young's modulus of rupture was recorded. XRD analysis was conducted onto the cooled ceramic.

3. Results and Discussion

3.1. Chemical Properties
Figure 1 illustrates the FTIR spectrum of WSD powder to inspect the purity of wood in the raw material. Since the common components present in woods are hemicellulose, cellulose and lignin, the peaks in the region between 1100 and 1800 cm^{-1} mainly exhibit the related functional groups [5]. A broad transmittance band at 3333 cm^{-1} indicates the hydroxyl (OH) groups of cellulose, showing the hydrophilic nature of the WSD. Moreover, C-H stretching of methyl and methylene groups can be observed at peak 2918 cm^{-1}. Collectively, the presence of the two peaks shows the organic matrix characteristic of the WSD. The transmittance of bands located at 1594 cm^{-1} and 1228 cm^{-1} were assigned to the C=C of aromatic groups and vibration of aromatic rings, respectively. Additionally, the C-O stretching of cellulose and lignin was shown by the strongest band at 1030 cm^{-1}. Thus, it was verified that the waste wood sawdust is indeed natural wood and organic substance.

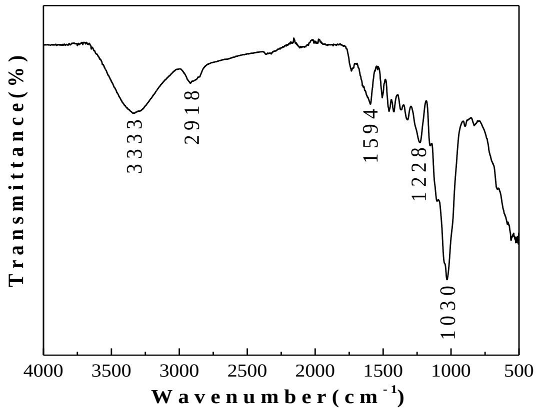

Figure 1. FTIR spectrum of WSD

3.2. Physical Properties

The percentage of water absorption for ceramic with 10 wt.% and 20wt.% of WSD is shown in Figure 2. Water absorption percentage of ceramic with 20 wt.% is 43.72% while the one with 10 wt.% WSD has a lower value of 29.95%. It shows that the percentage increases with an increase in WSD content in the composition. This is due to the porosity effect on the water absorption of porous ceramic, causing the water absorption increases with the addition of WSD [6].

On the other hand, Figure 2 also reflects the apparent porosity for the WSD incorporation of 10 wt. % and 20 wt. %. Based on the figure, the value of apparent porosity for the 10 wt. % is 39.54 % and increased for 20 wt. % WSD which is 46.63%. The porosity was produced during the firing process that eliminates the WSD from the structure, causing the pore to be formed. The higher porosity of the porous ceramic causes the apparent porosity to increase. Hence, the higher the composition of WSD, the higher the value of apparent porosity [7].

In terms of bulk density, the figure shows that the value of 10 wt. %, 1.32 g/cm^3, which is higher than 20 wt. %, 1.07 g/cm^3 composition of WSD. Hence, the addition of WSD in the composition reduced the bulk density due to the porosity that influenced the physical properties of porous ceramic. As the porous ceramic produced high porosity, the water absorption and apparent porosity were increased; however, it reduced the bulk density. Therefore, the result shows that the bulk density is inversely proportional to the water absorption and apparent porosity.

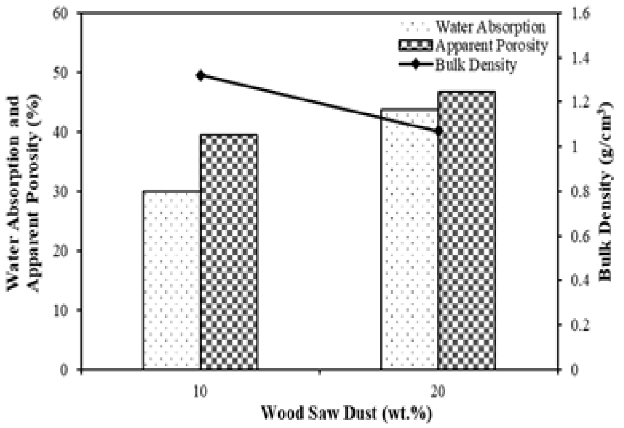

Figure 2. Water Absorption, Apparent Porosity and Bulk Density of Porous Ceramic

3.3. Mechanical Properties

A compressive test was performed to evaluate the mechanical properties of porous ceramic products. The results of Young's modulus and compressive strength of samples with different WSD content are presented in Figure 3. It shows that the mechanical strength of porous ceramic decreases as the composition of WSD increases. It was revealed in Figure 3 that Young's modulus of 10 wt.% is higher than that of 20 wt.% with 107.030 N/mm^2 and 100.088 N/mm^2, respectively, indicating that 10 wt.% able to withstand changes in dimension better than 20 wt.%. Hence, it can be concluded that the strength of mechanical properties shows a decrease as the addition of the organic waste product was added [8]. Significantly, the compressive strength shows reduction as the content of wood sawdust is increased with 27.347 N/mm^2 for 10 wt.% and 25. 694 N/mm^2 for 20 wt.%. It is due to the distribution of the pores that influenced the mechanical properties. The additive in the porous ceramic and its porosity properties is expected to affect the compressive strength [3]. Hence, the higher the porosity distribution, the lower the mechanical strength of porous ceramic.

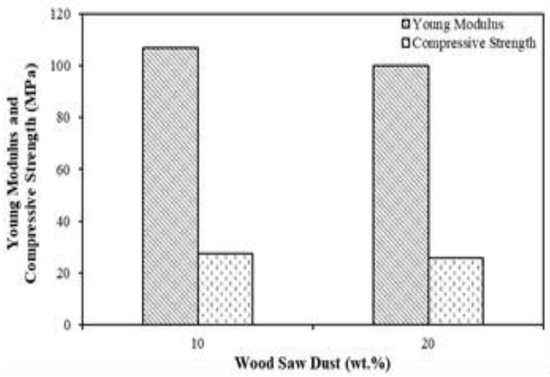

Figure 3. Young's Modulus and Compressive Strength of Porous Ceramic

3.4. Mineralogical Properties

Figure 4 compares the XRD pattern of china clay and ceramics containing 10 wt.% and 20 wt.% of WSD. It can be found that both china clay and porous ceramic are made up of mainly kaolinite and quartz. Kaolinite contributes 83.3% to the clay constituent while quartz with 16.7%. Phase transformation of kaolinite can be observed at the composition of 10 and 20 wt.% of WSD that were subjected to 900 ºC firing. The XRD analysis shows that quartz present at a very high amount of 84.2% while mullite only 15.8% in the 10 wt.% of WSD in the porous ceramic. However, for the porous ceramic containing 20 wt.% WSD, the presence of muscovite (53.3%), and quartz (46.7%) can be observed.

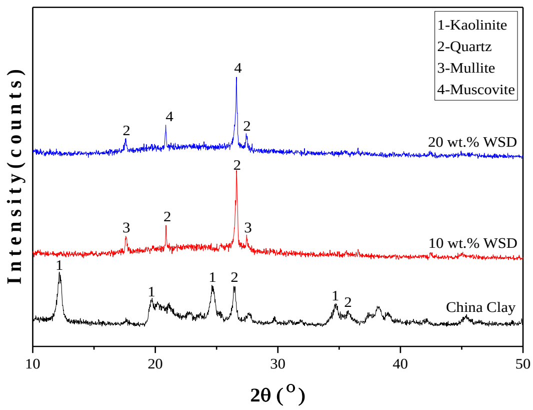

Figure 4. XRD Pattern of China Clay and Porous Ceramic Mix with 10 wt.% and 20 wt.% Wood Sawdust

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4. Conclusion

One of the more significant findings to emerge from this study is that porous ceramic could be produced from the waste wood sawdust due to the low ignition point and particle size that can be controlled from the sieving and firing process. This study has found that generally the composition of WSD has influenced the mechanical properties of the porous ceramic. A higher amount of WSD resulting in a lower compressive strength, while the percentage of water absorption and apparent porosity was increased. Ultimately, it is expected to reduce the usage of synthetic pore forming agent as it is an eco-friendly and non-toxic material.

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