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Preliminary Study of Utilizing Coconut Husk Waste as Pore Forming Agent for Clay Based Porous Ceramic

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ABSTRACT: This research aims to evaluate the suitability of coconut husk as a pore-forming agent (PFA) for porous ceramic products and to study the effects of coconut husk weight percentage and sintering temperature on porous ceramic physical and mechanical properties. Porous ceramic was produced by the sacrificial fugitive method. The physical properties were determined using water absorption test, apparent porosity, bulk density, linear shrinkage, and crystalline phase. The mechanical properties were determined using compressive strength. The results revealed that increase in the weight percentage of coconut husk (CH) in the porous ceramic decrease the compressive strength and increase the porosity. The highest strength of porous ceramic incorporated with coconut husk is 10 wt.% CH at 950°C sintering temperature and the lowest strength is 30 wt.% CH at 850°C sintering temperature. The well-balanced composition and sintering properties were obtained on the porous ceramic incorporated with 10 wt.% CH and 900°C sintering temperature.

Keywords: Coconut husk, pore-forming agent (PFA), porous ceramic

1. Introduction

Porous ceramics are defined as those with a high percentage of porosity ranging between 20 and 95 % [1]. Porous ceramics generally offer excellent mechanical strength, abrasion resistance, and chemical and thermal stability, among other characteristics. Porous network ceramic structures have low density, low mass, and poor heat conductivity and are relatively lightweight [2]. Apart from that, permeability is one of the essential qualities of porous ceramics for various applications, such as membranes, since this property is directly related to the amount of pressure drop experienced during the filtering process. When it comes to porous ceramics production, the management of pore size is the most important issue to consider [3].

In the production of porous ceramics, the ceramic powder was combined with the pore-forming agent in the ceramic (PFA). Pore-forming agents (PFA) used in the production of clay bricks may be divided into two categories which are inorganic (PFA) and organic (PFA). One way to increase the capacity of clay ceramic is to include inorganic pore-forming chemicals in the ceramic bricks. Organic pore-forming agents are often less expensive than inorganic pore-forming agents. Furthermore, they contribute to the sintering process by providing heat and reducing the amount of fuel required for the firing process. As a result, they are preferable to inorganic pore formers in many applications. To investigate waste materials in clay bricks, a wide range of waste materials has been studied, including kenaf waste, rice husk waste, bamboo waste, sugarcane bagasse waste, and other agricultural waste [4].

High moisture content of these organic (PFA) proved to be a limitation, particularly when preparing powder form PFA. The high moisture content of the agricultural waste will make the waste preparation process more challenging, especially during the grinding of the waste to generate the PFA powder. The inconsistency of the PFA's particle size distribution would affect porous ceramic properties such as porosity and compressive strength. It is anticipated that the low moisture content of coconut husk waste would enable the manufacturing of PFA powder to be more practicable with constant particle size. The waste with high moisture content is difficult to grind compared to waste with low moisture content. Therefore, the suitability of the coconut husk as a PFA in porous ceramic will be evaluated in this research.

2. Experimental

2.1 Simulation Design

Initially, coconut husk collected from agricultural industry was dried in an oven at about 70°C for 24 hours. The dried coconut husk was processed in a heavy-duty blender for 6 minutes and sieved through 250 µm sieve. Subsequently, the coconut husk powder was wet-mixed with China clay in accordance to the body formulation presented in **Table 1** to produce slurry mixture.

Table 1. Body formulation of clay based porous ceramics incorporated with coconut husk

Composition	China Clay (wt.%)	Coconut Husk (wt.%)
KC	100	0
KCCH10	90	10
KCCH20	80	20
KCCH30	70	30

The slurry was dried in an electric oven at 100°C for 24 hours. Next, the dried mixture was milled by using a mortar to produce powder mixture. Subsequently, the mixture was granulated in moist condition prior to compaction by uniaxial hydraulic press with pressure of 20 MPa. The compacted body was then dried in an electric oven at 100°C for 24 hours before sintering in furnace for 1 hour. Finally, the naturally cool porous ceramic was characterized in terms of water absorption, apparent porosity, bulk density, compressive strength and crystalline phases present.

3. Results and Discussion

3.1 Linear Shrinkage, Water Absorption, Apparent Porosity, Bulk Density and Compressive Strength

The linear shrinkage of porous ceramic incorporated with coconut husk was measured in accordance with ASTM C326-09 standard. **Fig. 1** shows linear shrinkage of the porous ceramic with different wt.% of CH and sintering temperatures.

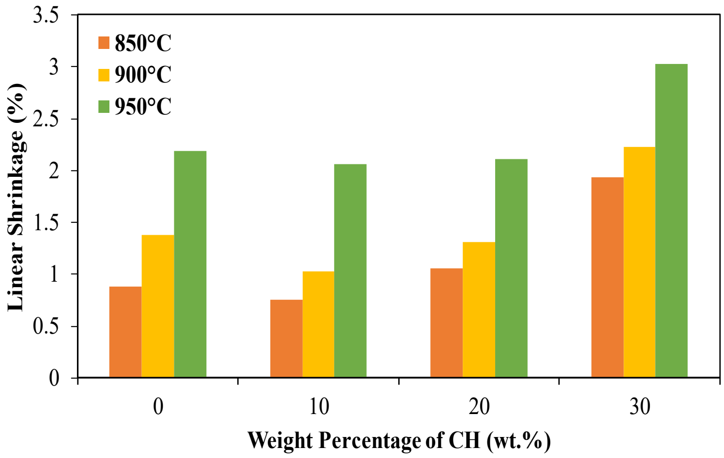


Figure 1: Linear shrinkage of the porous ceramic incorporated with 0 to 30 wt.% of CH

Fig. 1 shows the increased linear shrinkage of porous ceramic with the increased weight percentage of CH and the sintering temperature. Porous ceramic with 10 wt.% of CH with 950°C sintering temperature showed a slightly lower value than linear shrinkage with 0 wt.% of CH with the same sintering temperature. Despite that, the increased weight percentage of coconut husk will increase the porosity and pore size of the porous ceramic [5]. The linear shrinkage increases because of porosity, pore size, and binder ratio. The increasing temperature and linear shrinkage increase will shrink the porous ceramic. Characterization of linear shrinkage was performed and in the next section will be discussed the water absorption, apparent porosity and bulk density od porous ceramic incorporated with coconut husk.

Ceramic materials characteristics are significantly influenced by water absorption. Commonly, measurement of open pores is frequently done by measuring the water absorption [6]. This measurement is used ISO 10545 standard that describes procedures for evaluating porous ceramic water absorption, apparent porosity, relative density, and bulk density. The method that use to evaluate water absorption, apparent porosity and bulk density is vacuum method with using (100 ± 1) kPa pressure and vacuum around 30 minutes. **Fig. 2** shows water absorption of the porous ceramic with different wt.% of CH and sintering temperatures.

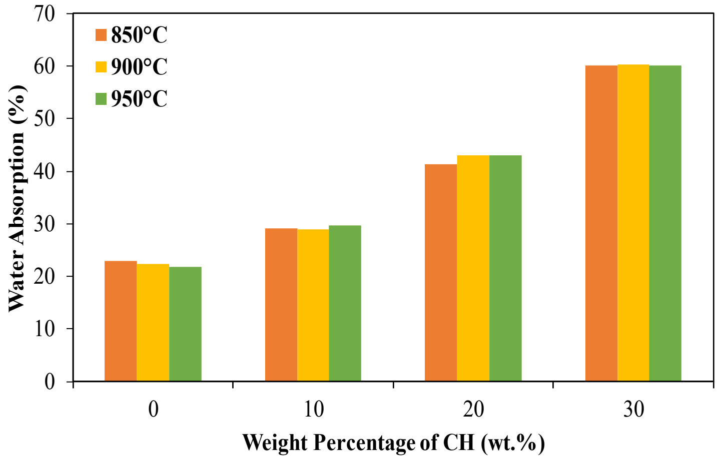


Figure 2: Water absorption of the porous ceramic incorporated with 0 to 30 wt.% of CH

According to Fig. 2, the water absorption of porous ceramic increased when the weight percentage of coconut husk increased. The sintering temperature also increases with increasing water absorption. The coconut husk was completely deposited in porous ceramic when the sintering temperature increased, and the coconut husk remained ash in the porous ceramic. Starting from sintering temperature 850°C to 950°C, the 30 wt.% of CH showed consistent water absorption and porosity. The increased porosity with increasing CH weight percentage. The apparent porosity and water absorption are related [7]. This is related to the results of apparent porosity. **Fig. 3** shows the apparent porosity of the porous ceramic with different wt.% of CH and sintering temperatures.

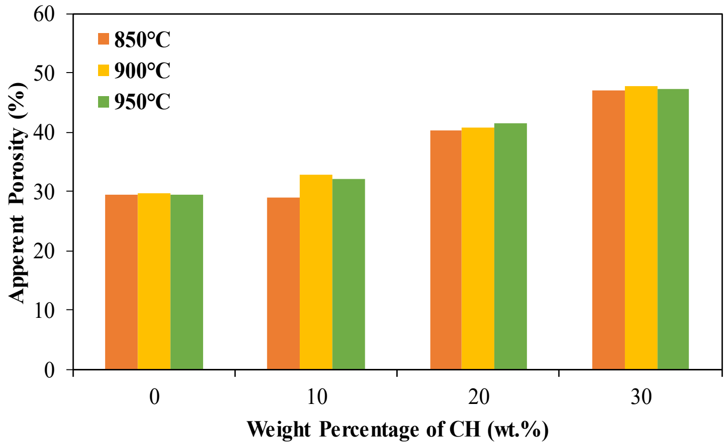


Figure 3: Apparent porosity of the porous ceramic incorporated with 0 to 30 wt.% of CH

The apparent porosity increased with the weight percentage of CH in the porous ceramic. The sintering temperature also increases with the increasing apparent porosity of porous ceramic. Therefore, the porous ceramic with 10 wt.% of CH at a sintering temperature of 900°C showed a slightly higher apparent porosity than the porous ceramic with the same weight percentage at different temperatures (850°C and 950°C). Same with the porous ceramic with 30 wt.% of CH at a sintering temperature of 900°C showed a slightly higher apparent porosity than the other sintering temperature. The relationship between apparent porosity and water absorption was shown by a similar trend. A higher percentage of water absorption resulted from an increase in apparent porosity. Higher sintering temperatures, however, can impact apparent porosity because optimal viscous flow can cover the porosity

[8]. This can be proven by bulk density results. **Fig. 4** shows the bulk density of the porous ceramic with different wt.% of CH and sintering temperatures.

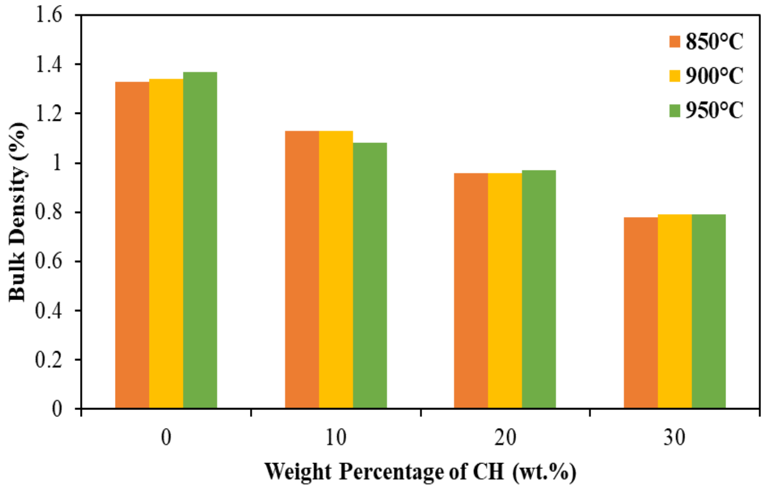


Figure: Bulk density of the porous ceramic incorporated with 0 to 30 wt.% of CH

According **Fig. 4**, the weight percentage of CH increased and the bulk density of porous ceramic is decrease. Meanwhile, the sintering temperature increased and the bulk density also increased. In spite of that, 10 wt.% of CH with 950°C is slightly lower that other sintering temperature.

In addition to apparent porosity, bulk density, and water absorption, compressive strength is important for the performance of porous ceramic. The objective is to determine the equilibrium between compressive strength and porosity. **Fig. 5** shows compressive strength of the porous ceramic with different wt.% of CH and sintering temperatures.

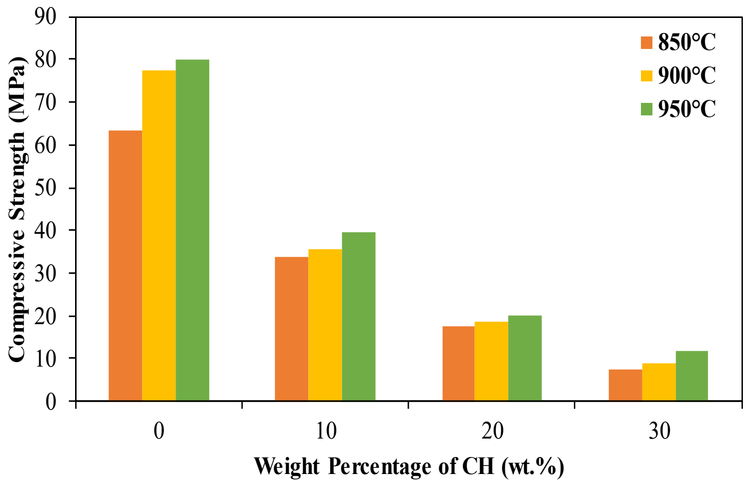
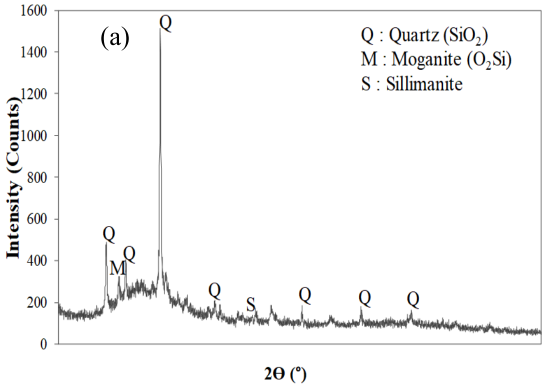


Figure 5: Compressive strength of the porous ceramic incorporated with 0 to 30 wt.% of CH

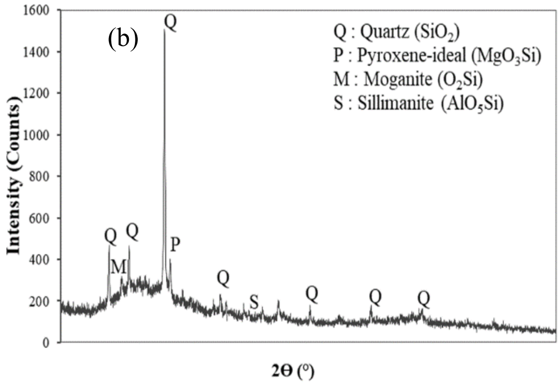
Based on **Fig. 5**, the weight percentage of CH increased, and the compressive strength of porous ceramic decreased. Meanwhile, the increasing temperature showed the opposite trend, which increased the compressive strength of the porous ceramic. This trend can describe the relationship of the apparent porosity. The number of open pores will increase as the apparent porosity percentage increases. The increase in open porosity and pressure concentration are correlated to a decrease in compressive strength [9]. The porous ceramic will have fracture bridging and crack closure due to increasing porosity [10].

3.2 XRD Phase Analysis

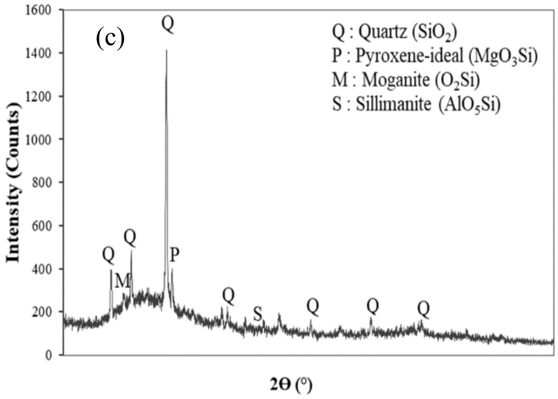
XRD phase analysis is to identify the main crystalline phases in porous ceramic incorporated with coconut husk by using different compositions and sintering temperatures. In this analysis, composition 30 wt.% with 850°C sintering temperature and 950°C sintering temperature with composition 0 wt.% CH, 10 wt.% CH and 30 wt.% CH were selected. The selection was to determine the crystalline phase on different compositions and sintering temperatures. **Fig. 6(a)** to **Fig. 6(d)** shows peaks of porous ceramic incorporated with coconut husk, respectively.



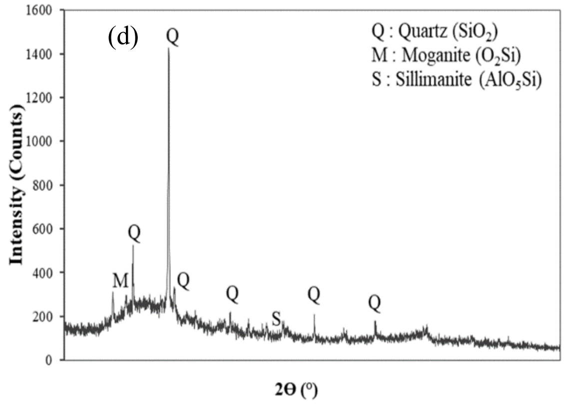
XRD peaks of porous ceramic with 30 wt.% CH and sintered at 850°C



XRD peaks of porous ceramic with 0 wt.% CH and sintered 950°C



XRD peaks of porous ceramic with 10 wt.% CH and sintered 950°C



XRD peaks of porous ceramic with 30 wt.% CH and sintered 950°C

Figure 6: XRD peaks of porous ceramic incorporated with coconut husk

Based on **Fig. 6(a)** and **Fig. 6(b)**, three distinct crystalline phases were observed in the porous ceramic incorporated with 30 wt.% of CH at 850°C sintering temperature and 0 wt.% of CH at 850°C sintering temperature: quartz, moganite, sillimanite and follow by pyroxene. The phase starts changing when the weight percentage of CH increases and stops changing when increasing the sintering temperature. The phases in the sample starting to disappear at high temperatures and completely change at higher temperatures [8]. This has proven why compressive strength at 0 wt.% of CH at 950°C sintering temperature has higher compressive strength, and 30 wt.% of CH at 850°C sintering temperature has slightly lower compressive strength. The increased compressive strength of the porous ceramic is a result of its decreased porosity. This has proven the bulk density of the porous ceramic incorporated with 0 wt.% 0f CH at 950°C sintering temperature is higher than 30 wt.% of CH at 850°C sintering temperature. Higher densification results in more closure of the pores, increasing the bulk density. Lower porosity will result from more closed pores. Moreover, according to **Fig. 6(c)** and **Fig. 6(d)**, the distinct crystalline phases were observed in the porous ceramic incorporated with 10 wt.% of CH at 950°C sintering temperature and 30 wt.% CH at 950°C sintering temperature, which is quartz, moganite, sillimanite, and pyroxene. Although the compressive strength of porous ceramic with 10 wt.% of CH and 30 wt.% of CH were lower than 0 wt.% of CH

(80.04 MPa), the compressive strength value for 10 wt.% of CH is 39.59 MPa higher than 30 wt.% of CH which is 11.85 MPa. The compressive strength is related to the hardness of the crystalline phase on the porous ceramic [11]. Every crystalline phase present in the porous ceramic has its own hardness value can be clarified by the Mohs hardness scale. **Table 2** shows the Mohs hardness scale of the crystalline phase in porous ceramic incorporated with coconut husk.

Table 2. Mohs hardness scale of the crystalline phase

Crystalline Phase	Mohs Hardness Scale	References
Quartz	7	[12]
Moganite	7.5 - 8	[13]
Sillimanite	6.5 – 7.5	[14]
Pyroxene	5 -7	[15]

Based on Table 2, all crystalline phases have an excellent Mohs hardness scale. This proven that even the 10 wt.% of CH have high porosity in porous ceramic, the Mohs hardness of each crystalline phase present in 10 wt.% of CH help to improve the compressive strength in this composition.

4. Conclusions

The project outcome showed the immense potential for using coconut husk as PFA in manufacturing porous ceramics. Coconut husk is found suitable to be used as PFA for porous ceramic product. The weight percentage and sintering temperature were found to significantly influence the physical and mechanical properties of porous ceramic. The highest strength of porous ceramic incorporated with coconut husk is 10 wt.% of CH at 950°C sintering temperature and the lowest strength is 30 wt.% of CH at 850°C sintering temperature. Along with, the highest apparent porosity is 30 wt.% of CH at 900°C sintering temperature and the lowest apparent porosity is 10 wt.% of CH at 850°C sintering temperature. Hence, the well-balanced composition and sintering properties were obtained on the porous ceramic incorporated with 10 wt.% of CH and 900°C sintering temperature.

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Conflict of Interest

The authors declare that they have no conflict of interest.

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