Abstract

This paper shows the results of a study of the change of physical properties of pottery due to adding different quantities of POP waste to the pottery powder mixture. The aim of this paper is a contribution to environmental protection and the demonstration of an opportunity to recycle POP waste. POP wastes produced by the local ceramics manufacturer were selected as filler in pottery. The pottery which was produced via the slip casting process and sintered at 950 °C, 1000 °C and 1050 °C and with different weight percentage of filler (0 wt. %, 2 wt. %, 4 wt. %, 6wt.%, 8wt.%, 10wt.%) into the composition. In the performed tests and examinations the characteristic properties of pottery like particle size, shrinkage, porosity and density were analyzed. The results and their interpretation show that POP can be used as filler in pottery ceramic.

1. Introduction

In recent years, critical issues concerning environmental damage caused by various productive sectors were the discharged of waste materials directly into ecosystems without adequate treatment. However, most researchers focus on great solution to recycle waste materials to reduce waste disposal problem in order to achieve sustainable development. It is very important for sustainable development of various ceramics industries and protection of the environment because the waste materials from industries would increase every year.

At a local ceramic industry in Johor, approximately 200,000 of Plaster of Paris (POP) waste was produced every month. After using the POP mould around 150 to 230 times, the mould is disposed of in landfills and often dumped directly into the environment. Nevertheless, other approach needs to be implemented to convert POP waste into materials that are fit for use and hence have commercial value to minimize the environmental impact. Therefore, it is crucial to discover new alternative to recycle POP wastes and evaluate the suitability of the POP waste in the fabrication of ceramic pottery after considering their potentialities as filler in ceramic processing.

Plaster of Paris (POP) is a white powder mixture of gypsum and a basic salt of calcium sulfate with a half molecule of crystallization (CaSO₄ ½ H₂O) [1]. Gypsum is an ionic mineral with the crystal structure consists of pairs of adjacent layers parallel to the b- axis containing the Ca²⁺ cations and the tetrahedral SO₄ anionic groups [2]. POP is used widely in ceramic industries as plaster moulds for slip casting for preparation of product according to desired shape [3]. Previous research has been carried out on the application of POP wastes into other material or products such as polypropylene [4], Portland cement [5], natural rubber [6] and concrete cube [7].

Generally, the temperature increases the rate of all sintering mechanisms and influences the characteristic of the ceramic structure and properties. Sintering is particularly crucial processes to produce hard and strong body by creating diffused particle for the ceramic production for the fabrication of ceramic [8]. Sintering carried out to the changes of ceramic properties such as shrinkage, porosity, density and strength...
The aim of the present study is to investigate the effect of adding POP waste and the effects of sintering temperature on the physical properties of ceramic.

2. Methodology

2.1. Material preparation

Solid wastes such as POP were generated by local ceramic factories and it was selected as filler in ceramic pottery fabrication. The solid POP mould was crushed by using a jaw crusher to produce fraction approximately 4mm in size. The POP wastes coarse and fine fraction was then milled by using planetary mono mill (Fritsch Pulverisette 6, Germany) at 230rpm for 10 minutes. Next, the milled POP was carried out into wet sieving size 25 μm. POP wastes slurry were sieved to an average particle of 25 μm and dried at 160 °C for 12 hours.

2.2. Slurry preparation

Slurry ceramics that had been prepared using powder raw material such as ball clay, kaolinite, potash feldspar, silica and POP wastes is given in Table 1. Silica was progressively substituted by waste POP.

| Mixture | Ball clay (wt %) | Kaolinite (wt %) | Potash Feldspar (wt %) | Silica (wt %) | POP (wt %) |
|---------|-----------------|-----------------|-----------------------|---------------|------------|
| 1       | 40              | 25              | 25                    | 10            | 0          |
| 2       | 40              | 25              | 25                    | 8             | 2          |
| 3       | 40              | 25              | 25                    | 6             | 4          |
| 4       | 40              | 25              | 25                    | 2             | 8          |
| 5       | 40              | 25              | 25                    | 0             | 10         |

The ratio of mixture powder ceramic with water was 30:70 by using agitator and the slurry was left 24 hours for the ageing process.

2.3. Drying and sintering process

The samples were dried at 100 °C for 3 hours in an oven and sintered at three different temperatures which are 950, 1000 and 1050 for 7 hours with the heating and cooling rate of 2.6 °C/min.

2.4. Characterization

The POP powder was characterized by using the CILAS particle size analyzer to determine the particle size distribution after the sieving process in the range of 25 μm. Shrinkage testing was measured by the diameter of the sample before and after sintering process by using vernier caliper (digimatic, Mitutoyo). The linear shrinkage for length, width, thickness of samples ceramic bar was calculated using given formula.

\[ \text{Percent shrinkage for } L = \frac{L_0 - L_1}{L_0} \times 100\% \]  \hspace{1cm} (1)

\[ \text{Percent shrinkage for } W = \frac{W_0 - W_1}{W_0} \times 100\% \]  \hspace{1cm} (2)

\[ \text{Percent shrinkage for } T = \frac{T_0 - T_1}{T_0} \times 100\% \]  \hspace{1cm} (3)

Whereas:
- \( L \) = Length of the sample
- \( W \) = Width of the sample
- \( T \) = Thickness of the sample
- \( L_0 \) = Length of the sample before sintering (mm)
- \( L_1 \) = Length of the sample after sintering (mm)
- \( W_0 \) = Width of the sample before sintering (mm)
- \( W_1 \) = Width of the sample after sintering (mm)
- \( T_0 \) = Thickness of the sample before sintering (mm)
- \( T_1 \) = Thickness of the sample after sintering (mm)

The porosity and density of sintered samples were measured by using Metter Toledo density Kit following Archimedes principle (ASTM 372) using and determined by using given formula:

\[ \text{Porosity, } P = \frac{W_w - W_{d}}{W_w - W_{s}} \times 100\% \]  \hspace{1cm} (4)

\[ \text{Bulk Density, } \rho = \frac{W_d}{W_d - W_{s}} \]  \hspace{1cm} (5)

Whereas:
- \( W_d \) = mass of air dried specimen (mg)
- \( W_s \) = mass of immersed specimen in liquid (mg)
- \( W_w \) = mass of immersed specimen in air (mg)

3. Result and discussion

3.1. Particle size distributions

The size distribution of the POP powder during slip casting, drying, and sintering influences the physical properties of the ceramics pottery. The result of particle size shown in figure 1. From table 2, there are three measurements of particle size distribution at 10%, 30%, and 60% point of the cumulative value. It shows that the largest size at 60% point is 8.66 μm meanwhile the lowest at the point of 10% is 1.18 μm. Therefore, it has been proven that the particle size distributions are in the range of lower than 25 μm.

Table 2. Particle size distribution of POP powder

| Particle Size (μm) | Cumulative value (%) | Particle Size distribution (μm) |
|-------------------|----------------------|---------------------------------|
| 25                | D_{10}               | 1.18                            |
|                   | D_{30}               | 3.51                            |
|                   | D_{60}               | 8.66                            |
3.2. Shrinkage

Additive POP wastes and sintering temperature affect the bar sample dimension length, width and thickness. The result shows that POP additive increases linear shrinkage as shown in Figure 2, 3, and 4. In addition, the linear shrinkage obviously shows that the increase of sintering temperature produces a higher shrinkage percentage. This may happen due to sintering where densification eliminates pore causes the increment of shrinkage. Further analysis also reveals that the increment of the porosity tent to cause the increment of linear shrinkage [10].

3.3. Density and porosity

Figure 5 shows the percentage of porosity for the adding POP weight percent that were fabricated with different temperature. The graph plots show that the sintered samples with 1050°C produces a lower percentage of porosity meanwhile the sintered samples with 950°C produces a higher percentage of porosity for each increment of additive POP weight percent. Further analysis also reveals that percentage of porosity decreases from temperature of 950 °C until reach 1050 °C. This may happen at temperature of 1050 °C that the number of pores and void spaces decreases. Furthermore, additive POP wastes produce an increased percentage of porosity because POP is a highly porous ceramic material with a relatively large internal surface consisting of interlocking crystal. This condition is noticed during the sintering process generated shrinkage when it tends to lower down the percentage porosity of the sintered samples [11].

As shown in figure 6, it reveals the increasing percentage of bulk density with the increment of sintering temperature. The graph also shows that there are differences in percentage of the bulk density sintered samples with additive POP wastes. It produces the increment bulk density by 4% POP wastes but decline gradually till it attains 10% of POP waste. As mentioned in previous studies, properties of porosity and density are interrelated to one another. In contrast, when the density increases, the porosity decreases.
4. Conclusion

The study has revealed that the different percentage of POP waste and sintering temperature influence the physical properties of pottery. By the addition 2 to 10 of weight percentage has proven to increase the percentage of shrinkage and porosity. Increment in sintering temperature has successfully improved the density for each increment of POP wastes. The success can be explained by the POP waste as filler in the pottery ceramic body in for its sustainability.

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