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Effect of alumina addition on physical and structural properties of ceramic porcelain

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Abstract. Porcelain usually made up of kaolin, feldspar, silica and alumina have properties as an electrical insulator. The effect of adding different amounts of alumina into the porcelain composition has revealed the positive possibility in the production of the ceramic insulator. The different types of raw materials which are feldspar, silica, kaolin and alumina used in the production of porcelain insulator samples by varying their composition. The properties of the porcelain sample after being sinter at 900 °C were identified according to their physical and structural properties. The porcelain sample properties were investigated using XRD, XRF and density test. The presence of corundum, quartz, albite and mullite phases was believed to increase the physical and structural strength of the porcelain sample.

1. Introduction

Porcelain insulators are mostly used as insulators for more than 160 years compared to the other type of insulator [1]. Porcelain insulator made from a mixture of kaolin, ball clay, fluxing agent and filler which are quart or alumina, then firing at very high temperatures to reduce the formation of pores. Clay as the main ingredient in the ceramic application will provide good plasticity for body forming. The silica or quartz is the example of filler material that only forms a high viscous liquid at high temperature while remaining stable at low temperature meanwhile the fluxing agent such as feldspar will form a viscous liquid during sintering process and aids in vitrification [2].

The porcelain insulator needs to have high strength, low water absorption and high dielectric properties to act in the electrical application. In a previous study, the high addition of kaolin clay affected the properties of the porcelain body. For example, a high amount of kaolin will result in a high percentage of water absorption [3]. Higher use of kaolin also will be caused the increase of the sample body shrinkage % and a decrease in the sample bulk density, which result in the reduction of sample strength.

As the solution to this problem, the amount of kaolin suggested being reduced and replace it with other material. Alumina is the most suitable material to be used as it has properties to increase the electrical resistivity and at the same time increase the mechanical strength of the sample. The addition of alumina will reduce the formation of quartz glassy phase as the alumina was proven to not undergo

any phase transformation [4]. This will make sure the stability of the porcelain grain structure from facing any crack or structure deformation.

In this study, the structure of the porcelain insulator will be identified by varying the composition of alumina and kaolin. The samples will be sintering at a high temperature in order to identify the changes in properties. The structure and physical properties of the sample before and after the sintering process will be analyses by using XRD, XRF, and density test.

2. Experimental

2.1. Materials.

The base composition of the porcelain insulator was prepared using 20 wt. % of feldspar, 10 wt. % of silica, with varying wt. % of kaolin and alumina. Clay or kaolin ($Al_2O_3.2SiO_2.2H_2O$) obtained from R & M Chemical. Feldspar ($K_2O.Al_2O_3.6SiO_2$) obtained from Sibelco Malaysia, silicon dioxide (SiO_2) are from HmbG Chemicals and aluminum oxide (Al_2O_3) obtained from Bendosen. The kaolin and feldspar were placed in an oven at a temperature of 105 ± 5 °C for 24 hours to remove the moisture content. Then, the kaolin and feldspar were passed through 120 μm mesh sieve to obtain a uniform particle size of 120 μm. Meanwhile, the alumina and silica were passed through 80 μm mesh sieve to obtain a particle size of 80 μm. The five different compositions of porcelain insulators were prepared by varying the composition of kaolin and alumina as shown in Table 1.

Table 1. The composition of raw materials with varying alumina and kaolin.

Code	***Feldspar (wt. %)***	***Silica (wt. %)***	***Kaolin (wt. %)***	***Alumina (wt. %)***
$K_{50}A_{20}$	*20*	*10*	*50*	*20*
$K_{45}A_{25}$	*20*	*10*	*45*	*25*
$K_{40}A_{30}$	*20*	*10*	*40*	*30*
$K_{35}A_{35}$	*20*	*10*	*35*	*35*
$K_{30}A_{40}$	*20*	*10*	*30*	*40*

2.2. Sample preparation.

All the raw materials, feldspar, silica, kaolin and alumina were weighted according to a different composition. Materials were mixed by using ball milling for 30 min/rotation and repeated up to 8-10 times until its homogenous. 4 drops of 5% polyvinyl alcohol (PVA) were added to the composition in the mixing process.

Porcelain samples were compacted by a hydraulic press machine with a pressure load of 160 MPa to form testing pellets with circular shape (10 mm diameter and 1-2 mm thickness). The compaction process was held for 2 minutes before the green body was taken out from the mould. The samples were sintered at 900 °C with 4 hours soaking time.

2.3. Sample characterization.

XRD is used to identify the sample phases, structures, crystal orientation, crystallinity, and crystal defect by using the Bruker D2 Phaser. XRD also used to identify the composition of minerals of the porcelain sample. The sample is proceeded for XRD after the sintering process using bulk sample. Meanwhile, XRF is used to detect the unknown element of the porcelain sample by using Bruker S2 Ranger. The result in table form providing the different concentration or percentage of the elements in the chemical composition. The sample powder is going to prepare less than 75 μm and prepare by grinding the powder using a pestle and sieved to the needed size. The sample powder needs to be compacted to form a pallet shape. The bulk density of each sintered sample is measured by the water immersion technique. The sample was dried and weighed in air and then immersed in a beaker of water. The bubbles can be observed as the water filled the sample's pores. The sample weight in the air and liquid was measured and recorded. The bulk density of the sample was calculated using Equation 1.

$$\rho = \frac{W_o - W}{W_o} \rho_o \qquad \text{Equation 1}$$

3. Results and Discussion

3.1. X-Ray Fluorescence (XRF)

The XRF data of the feldspar minerals chemical composition is shown in Table 2. The data had shown that potassium (K) and silicon (Si) were found to be the major constituents of the minerals. The XRF analysis had confirmed that the feldspar used are potassium feldspar [$K_2O.Al_2O_3.6SiO_2$] or also known as potash feldspar due to the potassium was found to be the major constituents of the minerals, which is 42.4%. Potassium feldspar can produce a product with higher strength, viscosity and transparency compared with the sodium feldspar [5]. The analysis also showed that feldspar could be the sources of silica (SiO_2) due to the high amount of silicon element found in the constituents which are 48.1%.

Table 2. The elemental analysis of feldspar minerals.

Element	Concentration (%)
Al	8.360
Ca	0.503
Fe	0.213
K	42.40
Mg	0.241
Rb	0.163
Si	48.100

The chemical composition of kaolin minerals obtained from the XRF analysis is shown in Table 3. The analysis had confirmed that the major constituents of the minerals found were silicon (Si) and aluminum (Al) which are 67% and 28.7% respectively. According to Jamo and co-researchers [6], kaolin in Malaysia has a high amount of silica and alumina content. However, the XRF result also showed that

kaolin mineral contains other impurities which are 1.17% Fe, 1.3% K, 0.535% Mg, 0.138% P, 0.152% S and 0.961% Ti.

Table 3. The elemental analysis of kaolin minerals.

Element	Concentration (%)
Al	28.700
Fe	1.170
K	1.300
Mg	0.535
P	0.138
S	0.152
Si	67.000
Ti	0.961

3.2. The X-Ray Diffraction (XRD)

Based on Figure 1, the XRD analysis shows the presence of the phase are corundum, albite, quartz, and mullite. The intensity of corundum (Al_2O_3) peak distribution increased from sample $K_{30}A_{40}$ to sample $K_{50}A_{20}$ after being sintered at 900 °C. The high crystallinity of corundum (COD 5000092) phases with a peak of 2θ at 25.5°, 35.1°, 37.7°, 43.3°, 57.4°, 66.4°, 68.1°, and 77° had been proved with the previous study that using alumina in their composition [7]. It's has been proved that corundum phases are the main component that presence in the distribution due to the high amount of alumina in the composition.

The intensity of the quartz (SiO_2) phase (COD 2100188) at 2θ= 26.6° increased from sample $K_{30}A_{40}$ to sample $K_{50}A_{20}$. Quartz will not change its structure within the amorphous phase when sintered at low temperature (800 °C) but only start to crystallize only after being sintered at 1000 to 1600 °C [8]. However, in this study, the samples already start to crystallize when sintered at 900 °C. The high crystallinity of albite (COD 9000702) phases was corresponding with a study by a previous researcher, which found the albite phases is at 2θ= 28° [9]. The highest intensity of albite ($NaAlSi_3O_8$) was found at sample $K_{35}A_{35}$. It is might due to the increase in wt. % of kaolin and the presence of feldspar in the composition. However, the albite intensity starts to reduce from sample $K_{40}A_{30}$ to sample $K_{50}A_{20}$, which might due to the insufficient amount of sintering temperature to produce a high crystallinity of albite phase when the amount of kaolin wt. % start to increase.

Moreover, the presence of mullite (COD 9001321) also had been proved to be found at 2θ= 26° [10]. The low intensity of mullite ($3Al_2O_3.2SiO_2$) was founded due to it does not fully crystallize yet as it is newly formed. According to Meng et al., (2016), the mullite phase was formed due to the decomposed of feldspar and kaolinite phase during the sintering process [11]. The study also stated that the small intensity of the mullite phase formed might have some defects such as dislocation and lattice holes. However, the formed of the mullite phase can be contributed to the increasing densification and mechanical strength of the porcelain sample [12].

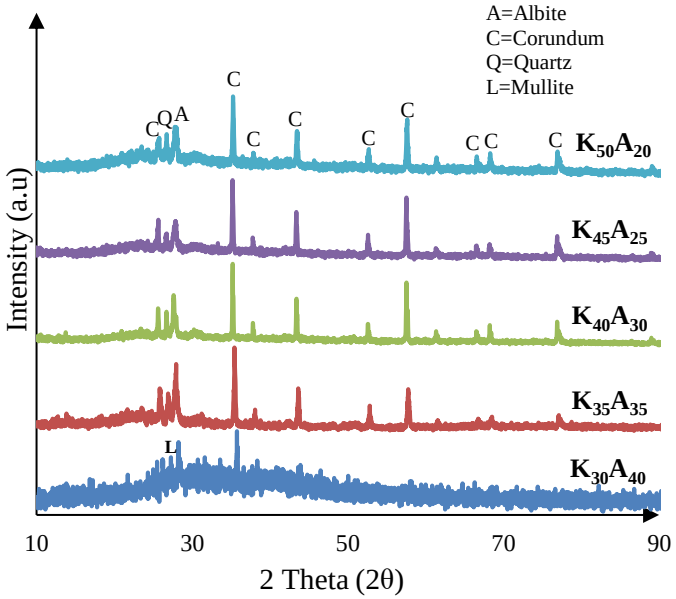

Figure 1. The XRD pattern of different compositions of samples.

3.3. Density

Figure 2 shows the density of the composition used. Sample $K_{30}A_{40}$ shows the highest value of density compared with other compositions, which are 2.90 g/cm^3. The value starts to reduce for sample $K_{35}A_{35}$ with density value obtain was 2.77 g/cm^3, followed by sample $K_{40}A_{30}$, 2.67 g/cm^3, sample $K_{45}A_{25}$, 2.66 g/cm^3 and finally sample $K_{50}A_{20}$ with the density value of 2.62 g/cm^3. As the wt. % of alumina increase and the wt. % of kaolin decreases, the density value of the porcelain body becomes higher. The higher value of sample density might due to the raising of melt phases in the porcelain body during the sintering process [13]. The glassy phase formed during the sintering process can close up the pores and increase the sample density. The high amount of glassy phase of alumina can reduce the pore formation in the porcelain insulator [14].

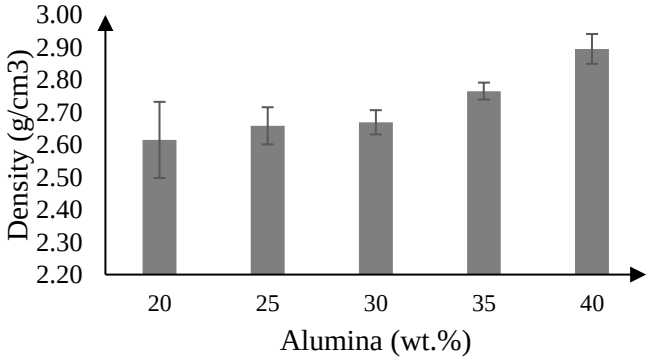

Figure 2. Effect of sintering temperature on the density of the samples.

4. Conclusion

The properties of porcelain insulator fabricated by using different types of raw materials which are feldspar, silica, kaolin and alumina were analyzed. The different compositions used gave a difference in the physical and structural properties of porcelain produced after sintered at 900 °C. It can be concluded that the sample with the highest amount of alumina has a low crystallinity distribution of the XRD

pattern. However, it has a high value of density, due to the presence of high intensity of the mullite phase which is one of the reasons for the increase in densification.

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References

[1] Contreras J E Gallaga M and Rodriguez E A 2016 *Annual Report - Conference on Electrical Insulation and Dielectric Phenomena, CEIDP*, *2016–Decem* pp 583–586
[2] Kitouni S and Harabi A 2011 *CerâMica* **57** pp 453–460
[3] Nwachukwu V C and Lawal S A 2018 *IOP Conference Series: Materials Science and Engineering* **413** pp 1–8
[4] Sedghi A, Riahi-Noori N, Hamidnezhad N & Salmani M R 2014 *Bulletin of Materials Science* **37** pp 321–325
[5] Aliyu Z S, Garkida A D, Ali E A and Dauda M 2016 *Characterization of Minerals, Metals, and Materials 2015* pp 291–297
[6] Jamo H U and S G A 2014 *Science World Journal* **9** pp 33–37
[7] Mehta N S Pandey J C Pandey N Pyare R and Majhi M R 2018 *Materials Research Express* **5** pp 1–16
[8] Zhang G Xu Y Xu D Wang D Xue Y and Su W 2008 *High Pressure Research* **28** pp 641–650
[9] Serdengeçti M T Baştürkcü H Burat F and Kangal M O 2019 *Minerals* **9** pp 1–11
[10] Matalkah F and Soroushian P 2018 *Construction and Building Materials* **158** pp 42–49
[11] Meng Y Gong G Wei D and Xie Y 2016 *Applied Clay Science* pp 1–8
[12] Ngayakamo B and Eugene Park S 2019 *Science of Sintering **51*** pp 1–10
[13] Sedghi A, Hamidnezhad N and Noori N R 2012 *International Conference on Ecological, Environmental and Biological Sciences* pp 343–345
[14] Noori N R, Mamoory R S and Mehraeen S 2014 *American Ceramic Society Bulletin* **86** pp 9201-9203