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Production of Ceramic Materials from High Loading of Palm Oil Fuel Ash mixed with recycled Soda-Lime-Silica glass

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Abstract: The production of ceramic materials from high loading of palm oil fuel ash (POFA) mixed with recycled soda-lime-silica (SLS) is reported in this paper. Hence, experiment was conducted to investigate which composition of POFA and SLS give the best result of characterization to produce ceramic. The composition of POFA and SLS was set within 30 wt% to 80 wt% and sintered at temperature of 900℃ for 2 hours. SLS sample were prepared by collecting 20 glass bottles, crushed them into powder sample, grinding until it become homogenous and sieving with 50 µm micro-sieve and pelleted at a pressure of 3 ton for 5 minutes. Whereas the POFA sample, were obtained at the laboratory. Each composition of the sample was characterized under the percentage of mass loss, chemical bonding, crystalline structure, bulk and powder density, porosity value, and surface morphology by using high accuracy balance (4 d.p), Fourier Transform Infrared (FTIR), Bruker D2 PHASE 2nd generation X-ray Diffraction (XRD), Newton EJ-300 Portable Balance, AccuPyc II 1340 gas displacement pycnometer, and COXEM EM-30AX scanning microscopy (SEM) respectively. The result showed at 80 wt% POFA mixed with 20 wt% SLS has the highest amount of silicon dioxide (SiO_2) , greater bulk and powder density which is 2.1450 gcm^{-3} and 2.5765 gcm^{-3} respectively and with the reduction of POFA, the overall density is reduced. The highest quartz peak can be seen in 80 wt% POFA sample proved by XRD results. FTIR shows greater Si-O bond at 80 wt% POFA and 20 wt% SLS compared with other samples. Shows that higher amount of POFA will produce high quality ceramic like stoneware or porcelain.

Keywords: POFA, Soda-Lime-Silica, Ceramic

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1. Introduction

Awareness of using waste materials as an alternative in replacing certain elements in the production of ceramic or building materials by industry is increasing. In addition to being able to preserve the environment, usually the cost of using substitute is cheaper and eco-friendlier.

This research aims to investigate ceramic material properties by using waste material which is soda lime silica (SLS) admixture with Palm Oil Fuel Ash (POFA). To determine which composition, give the best results, each waste material was tested in different composition which is 80 wt% POFA to 30 wt% POFA. Then, measure their physical and structural properties. Thereby, the manufacturing cost may be reduced by applying this technique and this could be the future of new substitute in the production of ceramic.

Malaysia is one of the world's top producers of palm oil, responsible for nearly 41% of global production in 2009-2010 [2]. Because of the solid waste and ash produced are rarely reused, they end up pollute the environment and create several environmental hazards such as health problem (bronchi) and traffic hazard (smog) [3]. Hence, it should present a realistic solution to both the problem of landfill and the high cost of waste disposal, as well as global pollution.

The amount of unburnt carbon in POFA indicate the color of the POFA, it will become darker with the increasing of unburnt carbon [4]. The chemical composition of POFA reveals that it contains a large amount of silica, which is thought to have great potential for use as a cement and porcelain substitute. The vast volume of free silica obtained from the source provides a low-cost silica alternative for most industrial purpose.[4] [5].

Typical composition (wt%) of soda lime glasses is 70 SiO_2, 10 CaO, 15 Na_2O and other small amounts of oxides. The structural nature of silica glass, as well as multicomponent silicate glasses, is polymeric. Its essence is a structural framework made up of SiO_4 tetrahedra connected by a common oxygen atom at each of the tetrahedra's corners (Si-O-Si oxygen bridges). The Si-O bond have a strong bond due to its ionic-atomic character. The angles of this bond can be adjusted from $132°$ to $180°$, making the silicate framework flexible [6]. The indispensable condition of the glassy state's existence is the structure's flexibility. It explains SiO_2 unique glass-forming properties as well as silica glass's unusually low crystallization ability. Because of the flexibility of chemical bonding, SiO_2 can form a variety of polymorphie, including three low-pressure ones: quartz, tridymite, and crystobalite, each of which has two high- and low-temperature forms.

Since the atoms in soda lime glass have strong atomic connections and are closely linked, other chemicals have a hard time affecting its structure and corroding the glass. This makes it suitable for use around chemical, especially if tempered to improve thermal shock resistance.

Soda lime glass is used in a variety of sectors due to its popularity and widespread availability. It can be found as windows in architecture and construction, as bottles and containers in the packaging and food and beverage industries, and as a high voltage insulator in the electrical field. Because of its increased strength and chemical resistance, soda lime glass is also utilised in scientific applications for supplies such as petri dishes, and as a cheaper alternative to borosilicate glass items when tempered. It can also be found in consumer goods as décor, and the tempered variant is utilised in consumer bakeware.

2. Materials and Methods

POFA was grounded by using mortar as well as the SLS to reduce the particle size and improve reactivity. Then, POFA and SLS was sieved separately using a set of sieves (150 µm) to remove foreign particles and particles coarser than 150 µm. Next, POFA and SLS was mixed according to the composition in Table 1. After that, the mixed powder was pressed into a pellet with a hydraulic pressure machine (CARVER 3851) for 5 minutes at a pressure of 3 ton. Each composition has four pellets. Next, the pelleted sample was sintered inside the electric box furnace (Protherm PLF 130/15) for 2 hours at 900℃ with heating and cooling rate is 5℃/min.

Table 1: Composition of POFA and SLS sintered at 900℃

Batch composition (wt%)		Designation
POFA	SLS	
80	20	80POFA20SLS
70	30	70POFA30SLS
60	40	60POFA40SLS
50	50	50POFA50SLS
40	60	40POFA60SLS
30	70	30POFA70SLS

Each composition was tested to determine its physical properties such as bulk density, powder density and porosity using Archimedes' method and AccuPye II 1340 gas displacement pycnometer. The crystalline structure of POFA mixed with SLS was identified through Bruker D2 PHASER 2nd generation X-Ray Diffraction (XRD) and chemical bonds present in the sample was investigated by Fourier Transform Infrared (FTIR). While the surface morphology of the sample was identify using COXEM EM-30AX scanning electron Microscope (SEM-EDX).

3. Results and Discussion

3.1 Mass Loss

The result of percentage mass loss versus composition of POFA is presented in Figure 1. The result shows that the mass loss was directly proportional with the POFA content (wt%) after sintered at 900 ℃. This mass loss was caused by the elimination of residual water from the sample, the decomposition of the binder, the formation of liquid from the flux, and the formation of crystalline phases from amorphous material like POFA [7].

Table 2: Mass Loss result on different composition of POFA and SLS.

POFA (wt%)	SLS (wt%)	Mass Loss (wt%)
30	70	9.1783
40	60	14.7834
50	50	17.2394
60	40	18.1166
70	30	19.2066
80	20	29.5468

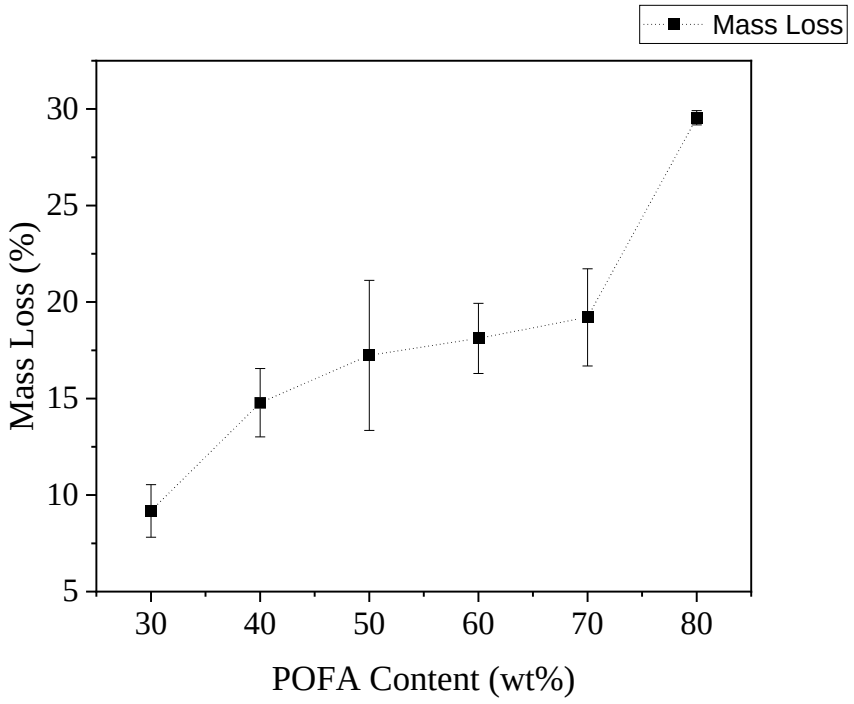

Figure 1: Graph of mass loss against palm oil fuel ash (POFA) at sintering temperature of 900℃.

3.2 Fourier Transform Infrared (FTIR).

FTIR spectra of POFA mixed with SLS at different composition are shown in Figure 2. The FTIR spectra of 30 wt% POFA mixed with 70 wt% SLS displayed a medium peak while at 80 wt% POFA and 20 wt% SLS shows a strong peak at range from $771cm^{-1}$ to $859cm^{-1}$. According to Lee et al. the bands at the range of 434 to 947 cm^{-1} were due to infrared absorption by the Si-O bond [8]. Shows that more Si-O bonds were formed in the composition of 80 wt% POFA with 20 wt% SLS than in composition of 30 wt% POFA with 70 wt% SLS. The lack of Si-O bond may be due to the Si-O bonds fission of the amorphous silica [9].

3.3 X-ray Diffraction (XRD).

The phase transformation developed in the sample at different composition of POFA mixed with SLS was studied. The XRD pattern in Figure 3 shows the mixture of POFA and SLS have a crystalline structure because of the sharp peaks pattern that is similar to the pattern reported in the Powder Diffraction Files of the International Centre for Diffraction Data [10] [11]. The peak between $25°(2\theta)$ to $30°(2\theta)$ increase with the increasing of POFA content. At 80 wt% POFA mixed with 20 wt% SLS has the highest peak because of the formation of quartz crystal (Q). This can be supported by the previous study [12] [9]. Due to POFA and SLS both have high composition of Silicon Dioxide (SiO_2), which is 66.9% in POFA [4] and 69.5% in SLS [9].

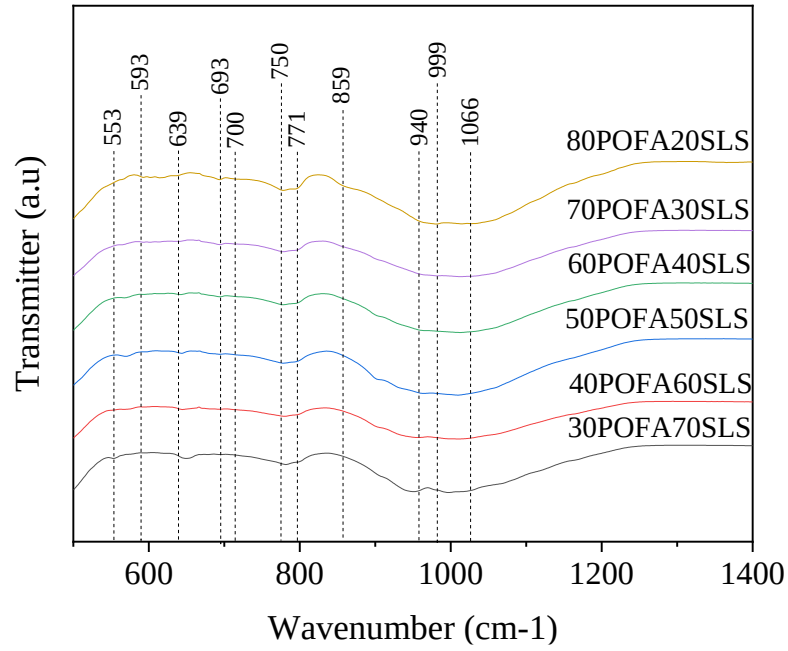

Figure 2: FTIR pattern of POFA mixed with SLS in different composition sintered at 900℃.

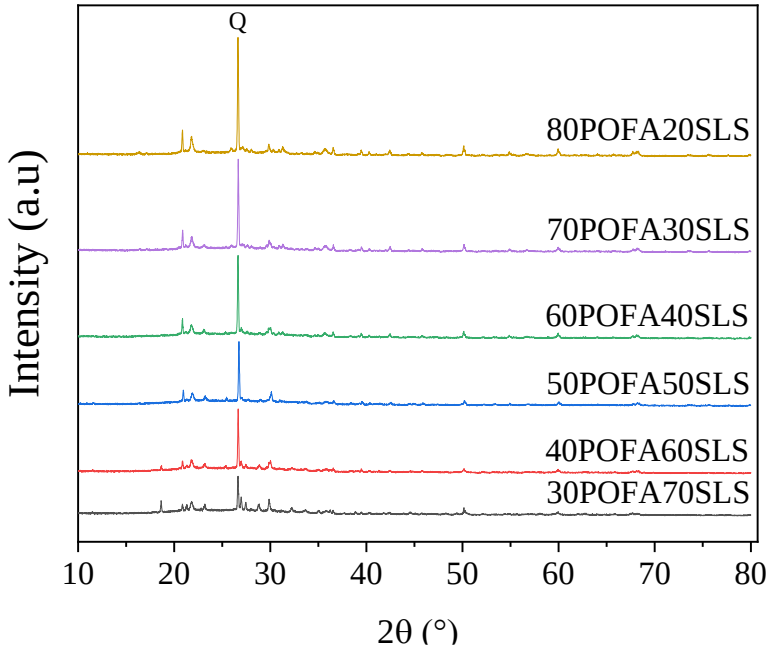

Figure 3: XRD pattern for different composition of POFA and SLS.

3.4 Density

Figures 4 shows the result of bulk and powder density for different POFA content based on Table 3. From Figure 4, the bulk density for each composition shows the positive and almost linear relation with the increment in addition of POFA. Similarly, with the powder density result that shows the increasing of density with the increasing of POFA content in the sample.

Table 3: Bulk and Powder density for different POFA content.

POFA (wt%)	Powder density (g/cm3)	Bulk density (g/cm3)
30	2.5198	1.2260
40	2.5176	1.1420
50	2.5227	1.1435
60	2.5415	1.5335
70	2.5556	1.7560
80	2.5765	2.1450

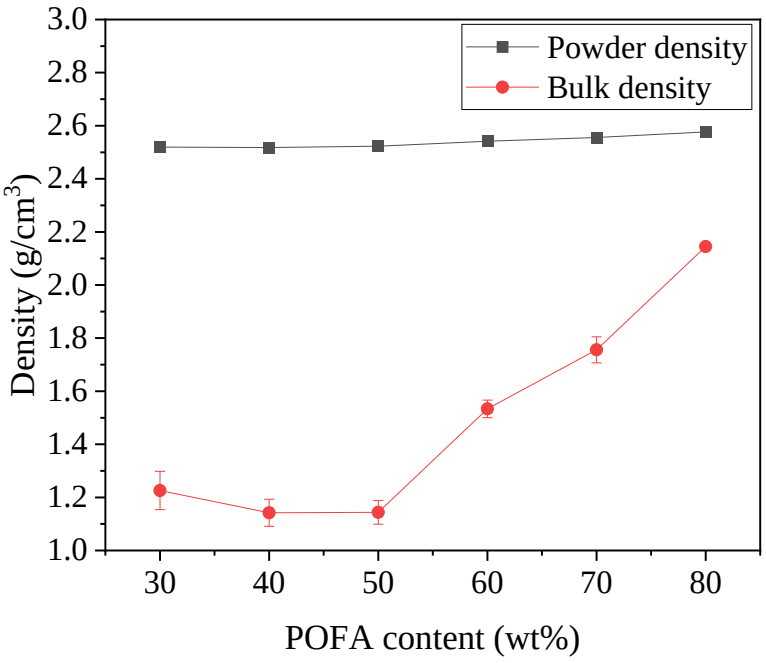

Figure 4: Bulk density and Powder density versus POFA content.

Sudden changes from 60 wt% to 80 wt% POFA could be due to the amount of POFA that started to react with SLS at a specific composition. The highest value of bulk and powder density occurs at the 80 wt% POFA mixed with 20 wt% SLS with a value of 2.145 g/cm3 and 2.5765 g/cm3 respectively. Similar results were obtained by Salem [13], where the greater bulk density values are due to the high amount of POFA in the composition. This could be owing to a decrease in internal pores when the amount of POFA is added [7]. Moreover, POFA have high inter-particle friction due to their shape. As mentioned by Ke et al., (2016), the behavior of sintering temperature toward the sample bodies may be affected by the changes in composition [14].

3.5 Porosity

From Figure 5 it is apparent that the porosity decreases with increasing POFA. The relation between density and porosity is reciprocal. The decrease could be due to the POFA particle size that is finer than SLS which is the average of POFA particle is (d_{30}) 5.40 µm [4]. Hence, when the amount of POFA composition is added and the SLS is decreasing, even with the same volume, the pallet become more compact and less pore space.

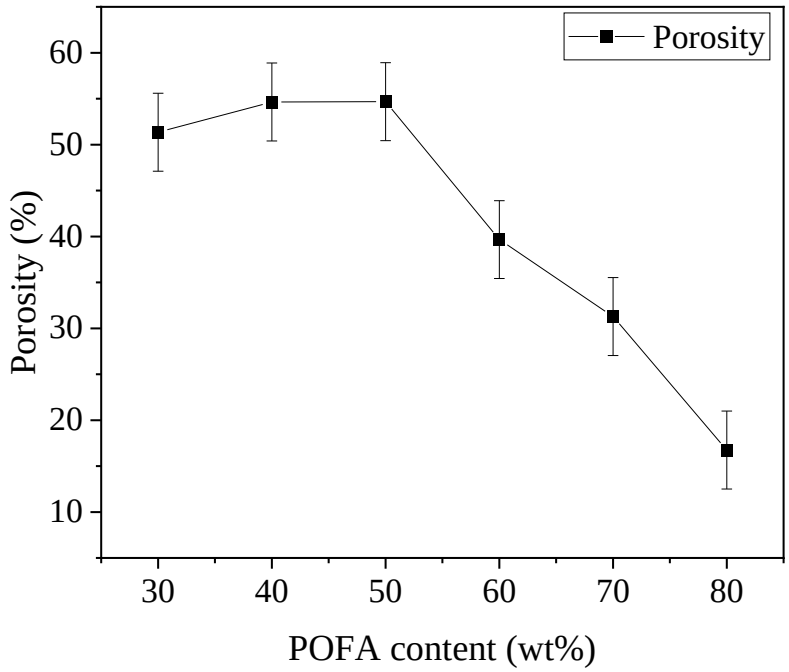

Figure 5: Porosity versus POFA content graph.

3.6 SEM-EDX

Figure 6(a) shows the SEM results of 70 wt% POFA mixed with 30 wt% SLS. The particles were irregular in shape and having porous texture. Calcium calcite can be seen in Figure 6(b). This is because both POFA and SLS have calcium oxide (CaO). Furthermore, this can be proven by using SEM-EDX results of spectrum 2, spectrum 3 and spectrum 4 in Figure 6(a) and Table 4. The table below shows the elements in the sample. The overall results show Silicon (Si), Oxygen (O) and Calcium (Ca) are the highest element in the sample.

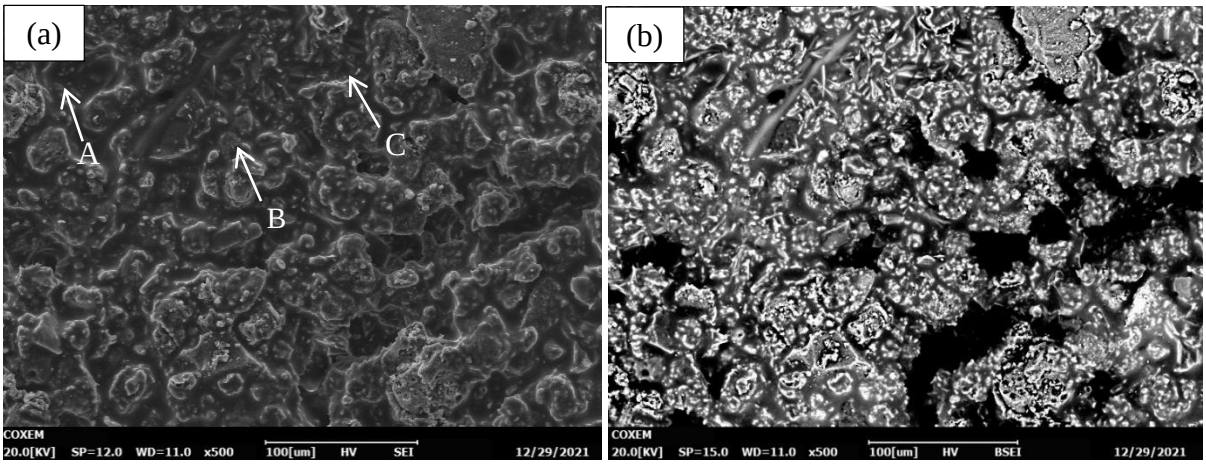

Figure 6: (a) SEM image (b) BSE image of 70POFA30SLS.

Table 4: Elements in selected area.

Element	Area A	Area B	Area C
	Atomic percent (at %)		
O	64.96	60.97	64.55
Na	3.64	4.80	3.90
Mg	1.93	0.93	1.65
Al	1.56	5.62	1.26
Si	20.85	21.25	21.64
K	2.05	2.92	2.24
Ca	2.98	2.18	4.08
Fe	0.98	0.48	0.36
Au	0.37	0.25	0.32
P	0.65	0.60	0.00
Ta	0.01	0.00	0.00
Total	99.98	100.00	100.00

4. Conclusion

Based on the experimental results and discussion, the following conclusions can be drawn:

The increasing of POFA content in the sample affects the sample density, porosity, crystalline structure, and morphological structure. The maximum density and minimum porosity from the experiment obtained at 80 wt% POFA mixed with 20 wt% SLS. The highest quartz peak can be seen in 80 wt% POFA sample proved by XRD results. FTIR shows greater Si-O bond at 80 wt% POFA and 20 wt% SLS compared with other samples. Shows that higher amount of POFA will produce high quality ceramic.

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