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Physical and Mechanical Properties of Porcelain Formed by Substituting Quartz with HCl Treated Palm Oil Fuel Ash

Sani Garba Durumin Iya[1]*, Mohamad Zaky Noh[2], Siti Noraiza Ab Razak[3] and Nur Azureen Alwi Kutty[4]

[1,2,4] Materials Physics Laboratory, Faculty of Applied Sciences and Technology, Universiti Tun Hussein Onn Malaysia, Pagoh Educational Hub, 84600 Pagoh, Johor, Malaysia.
[1]Power Equipment and Electrical Machinery Development Institute (PEEMADI) Okene, Nigeria.
[3] Centre for Diploma Studies, Universiti Tun Hussein Onn Malaysia, Pagoh Educational Hub, 84600 Pagoh, Johor, Malaysia.

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Abstract: Palm Oil Fuel Ash (POFA), is a waste material from palm oil industries that has potential of recycling in the porcelain production due to its high content of silica. POFA is produced by burning palm oil shells, empty fruit branches and fibers as a fuel to heat up the boiler for electricity generation in the industries. This research is aimed at producing porcelain with the substitution of treated POFA with quartz at 20 wt%. Treated POFA was dried in an oven for 24 hours at 110°C and ground using ball mill machine for 12 hours to get particle size <50μm. 20 wt% of POFA powder was substituted for quartz and mixed with the composition of porcelain for 12 hours and then pressed into pellets at a mold pressure of 91 MPa. The pellets were sintered at a temperature of 1200°C for 2 hours soaking time at a heating rate of 5°C per minute. It was revealed that the maximum density was achieved at 2.38g/cm^3 as the molarity of HCl is increased to 3 mole with the counterpart hardness of 7826 MPa. This improvement may be attributed to the increased in the silica content as a result of treatment of POFA with HCl acid.

Keyword: POFA; Porcelain; Hardness; Soaking time; Bulk density; Compressive strength

1. Introduction

Palm oil is a popular edible oil that is widely used to process food and other cooking activities [1]. In malaysia, palm oil industries are among the major industries that generate revenue and yield a huge amount of waste. To extract crude palm oil, huge amount of waste by-product in different forms are produced along with the crude palm oil such as empty fruit bunches, fibers, and kernels.[1]

According to [2], it is estimated that approximately 4 kg of dry biomass will be produced for the production of 1 kg crude palm oil. To save energy and fuels, the waste materials are often burned to heat up the boilers for generating power in palm oil factories. The resulted ash from the burning activity is known as palm oil fuel ash (POFA) [3].

Malaysia is among the largest producers and exporters of palm oil, thus in Malaysia alone, an estimate of 10 tonnes per year of total POFA waste is produced [3,4]. It is also reported that, in Thailand, it is estimated that more than 10 tonnes of POFA are produced annually, and this quantity is expected to increase every year. Evidently, the usage of POFA is low and discouraging which most of it is dispose at landfills. This can cause several environmental problems like floods and water pollution. Utilizing this waste from the palm oil industry as the composite and supplementary materials will not only enhance sustainability but will also solve the huge issues caused by this waste [5]. This research is aimed at determining the physical and mechanical properties of porcelain with quartz substitution by HCl treated POFA.

Extensive research has been performed on the possibility of using POFA in blended cement. It is conclude that since silicon dioxide is the main chemical constituent of POFA, it can replace cement partially as it acts as pozzolanic [6]. Previous researchers such as [7][8] sucessfully substituted quartz with POFA for the production of porcelain tile.

The term Porcelain refers to a wide range of ceramic products that are heated or baked at

*Corresponding author: d_iya4real@uthm.edu.my

penerbit.uthm.edu.my/ojs/index.php/jst

high temperatures to form vitreous and glassy materials that are visibly opaque or translucence. The composition of porcelain is highly variable, but the standard porcelain comprise of 50% clay, 25% feldspar and 25% quartz [9]. Porcelain vitrification indicates its high degree of melting point which in turn give rise to lower porosity (< 0.5%) and higher glass content (>0 40%) on fired porcelain [8]. Porcelains have high hardness, low electrical and thermal conductivities as well as brittle [10].

2. Methodology

To increase the reactivity of POFA, removal of unwanted materials such as carbon is necessary, Raw Palm Oil Fuel Ash was dried in an oven at 110°C for 24 hours. The powder was treated with 3 mole of HCl so as to obtain an optimum production of SiO_2, treated POFA was dried in an oven for 24 hours at 110°C to remove the moisture and ground using ball milling machine for 12 hours to get particle size <50µm. Standard porcelain composition of 50% clay, 25% feldspar and 25% quartz was used. HCl treated POFA was substituted at 20 wt% and mixed with the composition of porcelain for 12 hours and then pressed into pellets at a mould pressure of 91 MPa. The pellets were sintered at a temperature of 1200°C for 2 hours soaking time with a heating rate of 5°C per minute. The compressive strength and Vickers micro hardness were analysed using Universal Testing Machine (UTM) and (Shimadzu HMV-2 series) respectively. The physical properties such as the bulk density and porosity were also calculated using Mettler Toledo XS64 and P= ((W-D)/(W-S))*100 respectively. XRF Bruker S4 Pioneer which is operated at 60 KVP and 50Ma was uses a used to analyse the chemical compositions of the treated POFA powder and porcelain tile.

3. Results and Discussions

The chemical composition of treated POFA was analysed using X-ray fluorescence analysis (XRF), which was previously reported by [11][12] and [13]. As can be seen in Table 1, there is present of different compounds with SiO_2 as the major composition followed by C, Cl, CaO, K_2O, Fe_2O_3 and Al_2O_3 with compositions 59.77, 8.34, 8.21, 4.69, 4.65, 4.37 and 3.36 respectively.

Table 1 Chemical Composition of treated POFA

Compound	Composition (wt%)
SiO_2	59.77
C	8.34
CaO	4.69
K_2O	4.65
P_2O_5	3.20
Fe_2O_3	4.37
Al_2O_3	3.36
Cl	8.21
MgO	1.56
SO_3	1.34
LOI	0.49

The compressive strength and Vickers hardness of porcelain sample is presented in Fig 1. The highest value of compressive strength was achieved when POFA sample was treated with 3 mole of HCl with the value of 124.985 MPa, thereby the value decreased to 114.6 and 60.938 by 2 mole and 1 mole HCl respectively. This value was achieved due to the 3 mole acid treatment, probably because of the acidic reaction with chemical composition of POFA that lead to the increase in the production of SiO_2. Similarly, there is similar trends for Vickers micros hardness result which shows a steady increase from 7544, 7728 to 7822 MPa respectively for sample using POFA that treated by 1, 2 and 3 mole HCL. Similar result was reported by [9] when there is different trend in mechanical measurement this could be attributed to the absence of voids or enhanced dissolution of the raw materials of porcelain.

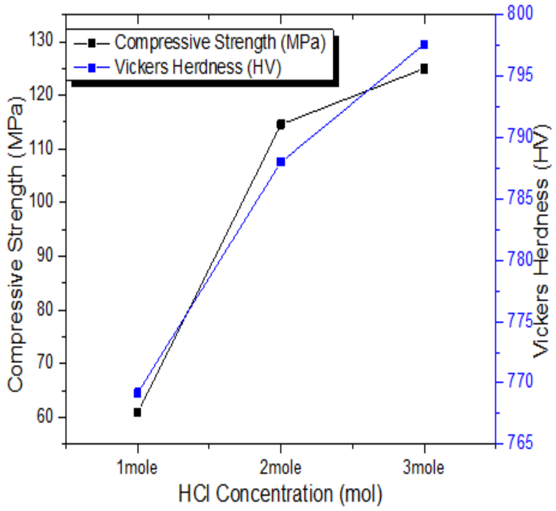

Fig. 1 Variation of compressive strength and Vickers hardness versus HCl concentration.

Bulk density and mass loss of the sample sintered at 1200°C is presented in Fig 2 below. The value of bulk density progressively increased from 1.99 to 2.29g/cm^3 for 1 and 2 mole treatment respectively, whereby the highest value of bulk density was achieved by 3 mole of HCl treatment at 2.38g/cm^3 and this could be as result of the higher concentration of HCl which leads to better purity of the silica. This also remove the volatile materials and reduced the porosity during heat treatment which leads to better densification. Previous researcher attributed this to sintering temperature [14].

Fig 2 shows percentage of mass loss that increase for 1 and 2 mole treatment, while there is a slight decreased for the 3 mole treatment.

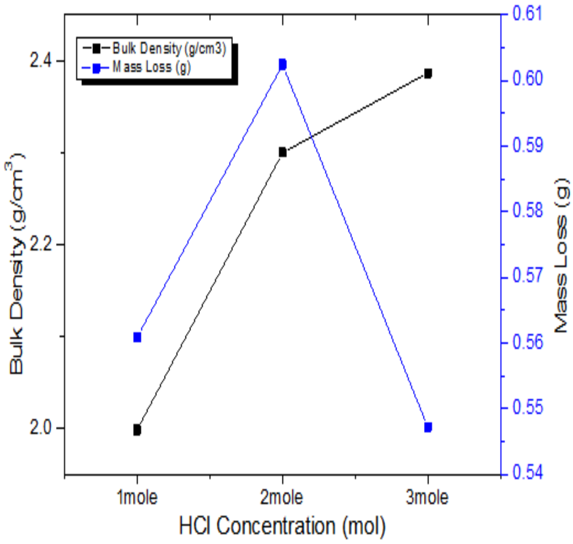

Fig. 2 Variation Bulk Density and Mass Loss versus HCl concentration.

The volume shrinkage versus acid treatment composition is plotted and presented in Fig 3 below, it may be observed that the volume shrinkage increase evenly at 1 and 2 mole treatment and later decrease to 12.24 % at 3 mole treatment, as a result of increased molarity of acid and its reaction with the POFA. This result suggested that sample treated with 2 mole of HCl give maximum value of density.

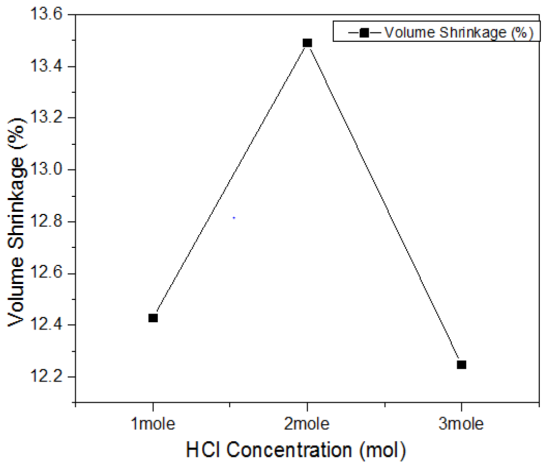

Fig. 3 Variation of Volume Shrinkage versus HCl concentration.

The Photomicrographs of the porcelain sample treated with 3 mole of HCl is presented in Fig 4 below. The presence of Quartz and mullite can be clearly noticed from Fig 4 due to 20 wt% substitution. As reported by [15], the micro-crack developed near the grains of quartz is due to formation of closed porosity, and normally happen as a result of stress during cooling process. From figure below it is also clear that there is uniform distribution and smooth interlocking between the mullite and quartz grain as reported by [16] this could lead to higher compressive strength.

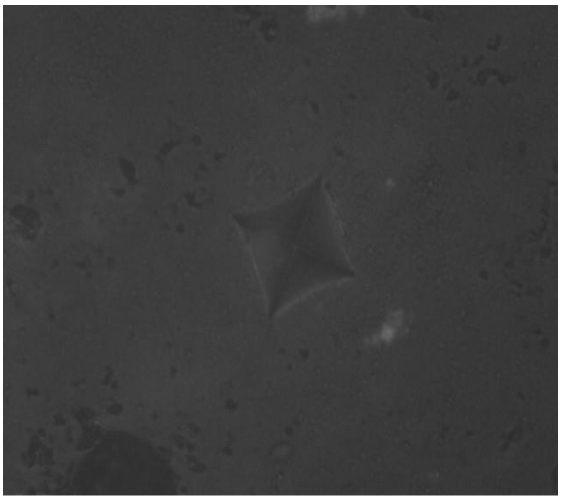

Fig. 4 Photomicrographs of Porcelain of sample treated with HCl concentration.

4. Conclusion

The determination of physical and mechanical properties of porcelain with substitution of quartz by POFA was studied. The compressive strength, Vickers micro hardness and density was found to increase by the substitution of quartz with treated POFA at 20wt%, with highest values of 124.985 MPa, 7822MPa and 2.38g/cm^3 respectively. Treatment of POFA with 3 mole of HCl enhance the production of silica and thus, presence of quartz and mullite leads to increase in the compressive strength of porcelain tile. Similarly, the increase in the bulk density and subsequent dissolution of grain and interlocking of the mullite and quartz may also increase the compressive strength, and it is also attributed to formation of glassy phase of the grains during the vitrification process.

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