Effects of Palm Oil Fuel Ash Composition on the Properties and Morphology of Porcelain-palm Oil Fuel Ash Composite

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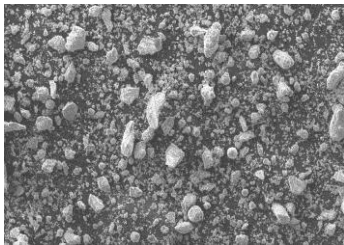
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Abstract

The increasing amount of disposed palm oil fuel ash (POFA) from palm oil industries has recently attracted significant attention for an alternative sustainable application. This paper presents the effects of the addition of a treated POFA on porcelain in terms of bending and compressive strength, as well as weight composition. POFA obtained from a palm oil mill was treated via sieving, grinding and heating at a temperature of 600°C for 90 minutes in order to the remove unburnt carbon and to improve the silica content of the POFA. Pellets made with various proportions of porcelain and POFA were fabricated and sintered at a temperature of 1200°C. The results reveal that the maximum bending strength and the compressive strength occurred at 8 wt% addition of POFA, Porcelain containing POFA has about 7% weight reduction compared with normal porcelain.

Keywords: Bulk density; compressive strength; POFA; porcelain; porosity

Abstrak

Peningkatan pelupusan bahan abu minyak sawit dari industri telah memburu satu alternatif untuk penggunaan mampan. Kertas kerja ini melaporkan kesan penambahan bahan abu minyak sawit terhadap sifat, mekanikal dan berat komposisi porselin. Bahan abu minyak sawit yang diambil dari kilang minyak sawit telah dirawat melalui proses ayakan, pengisaran dan pemanasan pada suhu 600ºC selama 90 minit untuk menyingkirkan karbon yang tidak terbakar dan untuk meningkatkan kandungan silika di dalam bahan abu minyak sawit. Pelet yang dihasilkan dengan pelbagai komposisi porselin dan minyak abu bahan sawit telah direka dan disinter pada suhu 1200ºC. Keputusan menunjukkan kekuatan lenturan maksimum dan kekuatan mampatan terhasil pada 8% berat penambahan abu bahan minyak sawit, semetara porselin mengandungi bahan abu minyak sawit telah menunjukkan pengurangan berat sebanyak 7% berbanding dengan porselin biasa.

Kata kunci: Ketumpatan pukal; kekuatan mampatan; bahan abu minyak sawit; porselin, keliangan

■1.0 INTRODUCTION

The oil palm industry in Malaysia accounts for over half of the world's total palm oil output and is set to grow further with the global increase in vegetable oil demand. However, it is also the main contributor to the nation's pollution problem, with the annual production of 2.6 million tonnes of solid waste in the form of Palm oil fuel ash [1]. An agro-waste ash that contains a large amount of silica. The current waste disposal practice of incineration within the industry is normally done in an uncontrolled manner and contributes significantly to atmospheric pollution [2]. Palm Oil Fuel Ash (POFA) is grayish in color, becoming darker with increasing proportions of unburnt carbon [3]. Its chemical composition indicates presence of a high mound of silica, which is considered to possess high potentials of serving as cement replacement

The utilization of palm oil fuel ash in high-strength concrete showed that POFA can be used as a pozzolanic material to produce high strength concrete. In addition, the utilization of POFA can improve concrete strength and permeability [4]. Moreover, partial replacement of OPC (Ordinary Portland Cement) with POFA helps sulfate resistance [4] and chloride resistance of concrete [5]. Compressive strength of cement paste containing pozzolan materials is contributed by hydration reaction, packing effect and pozzolanic reaction. Hydration reaction is the chemical reaction between Portland cement and water as pozzolanic compound and calcium hydroxide [6, 7]. The use of POFA as an additive ingredient also is expected to add value to the properties of porcelain.

Traditionally, porcelain is defined as a glazed or unglazed vitreous ceramic white ware and used for technical purposes, designating such products as electrical, chemical, mechanical,

structural and thermal wares when they are vitreous. Triaxial porcelain, primarily composed of clay, feldspar and a filler material (usually quartz or alumina), is considered to be one of the most complex ceramic materials. Commonly, clay–feldspar–quartz porcelains are referred to as tri-axial whiteware. On thermal treatment, the triaxial porcelain system forms a mixture of glass and crystalline phases depending upon the chemistry of the raw materials and processing science. Potassium oxide-alumina – silicon oxide ($K_2O–Al_2O_3–SiO_2$) and Sodium oxide- alumina-silicon oxide ($Na_2O–Al_2O_3–SiO_2$) [8-10] provide useful information on compositions for various types of industrial porcelains.

Several investigators [11, 15] tried to improve the mechanical properties of porcelain bodies by replacing quartz with other materials viz; rice husk ash and silica fume, fly ash, sericitic pyrophyllite, kyanite, bauxite, sillimanite sand, rice husk ash and alumina.

The alumina has a significant influence on the mechanical properties of white-ware due to the formation of primary mullite [16]. On the other hand, Prasad [15] showed that rice husk ash with minor or negligible amounts of carbon, incorporated in the whiteware composition, makes an improvement in the properties of porcelain. But the flabby nature of RHA particles which unfavorably influenced the output of body preparation and possibly increase the loss caused by cracking and deformation.

The present investigation therefore, is designed to utilize POFA as an additive ingredient in the porcelain body. Experimental parameters involved include volume shrinkage, porosity, bending strength, and compressive strength.

■2.0 EXPERIMENTAL

The removal of excess carbon and other unburned organic materials contained in untreated POFA is important to avoid their potential negative effects on finished product. Thus, the untreated POFA was dried in an oven at 100ºC for 24 hours. The untreated POFA was then grounded in a ball mill to reduce the particle size to improve reactivity. The milling time was approximately one and 1.5 hours at 200 rev/min. Then the untreated POFA was sieved using a set of sieves (150 μm) to remove the particles coarser than 150 μm. The untreated POFA was heated at a temperature of 600ºC for 1.5 hours in an electric furnace. After the heat treatment, the color of treated POFA turned from light brown to grayish red (Figure 3) when the unburned residue was removed.

Porcelain raw material powder was grounded separately in a ball mill. The powder was sieved using sieve shaker and dried in an oven. The treated POFA was incorporated into the body of porcelain powder from 2 wt% to 10 wt%. The composition was mixed using a ball mill for 1.5 hours. The mixed powder was pressed into pellets and bars at a pressure of 91 MPa. All the pellets and bars were sintered at a temperature of 1200ºC for 2 hours soaking time, at a heating rate of 50ºC per minute.

The physical and mechanical properties of the pellets such as volume shrinkage, porosity, bending strength, and compressive strength were determined. The chemical composition of the treated POFA was studied using X-Ray Fluorescence (XRF) while the crystalline structure of the treated POFA was identified through XRD and the microstructural features were studied by FESEM.

■3.0 RESULTS AND DISCUSSION

X-Ray Fluorescence (XRF) analysis is a proficient in analyzing material contents inside treated POFA, hence the amount of SiO_2 can be observed. The presence of various compounds within treated POFA, untreated POFA and porcelain raw material sample can be seen in Table 1. It is evident that SiO_2 is the major composition in the treated POFA, untreated POFA and porcelain raw material with 55.50 wt%, 43.20 wt% and 66.50 wt% respectively. Followed by alumina with 8.96 wt%, 5.67 wt% and 26.30 wt% respectively.

Table 1 Chemical analysis of POFA and porcelain

Composition	Wt (%) Treated POFA	Wt (%) untreated POFA	Wt (%) Porcelain Raw Material
SiO_2	55.50	43.20	66.50
Al_2O_3	8.96	5.67	26.30
CaO	8.81	15.16	0.45
K_2O	7.81	9.71	4.60
Fe_2O_3	4.28	3.25	0.42
P_2O_5	3.78	6.14	-
MgO	2.45	1.75	0.18
SO_3	2.11	3.10	
Rb_2O	-	-	0.14
CsO	-	-	0.13
CO_2	-	11.06	0.10
Cl	0.76	0.79	-
Na_2O	1.10	1.12	0.86
LOI	4.20	5.31	1.41

X-Ray Diffractometer is a mechanical device for obtaining X-ray intensities as a function of the angle between the incident and the diffracted beams. Figure 1 shows the result of phase diagram (called a diffractogram) indicated the crystalline phases quartz Q = Quartz, C = Cristoballite, G=Grossular (Ca_3Al_2 $(SiO_4)2(OH)_4$.). As it can be seen the peaks increased after the treatment. Hence, the treated POFA is expected to give more compressive strength because of silica content.
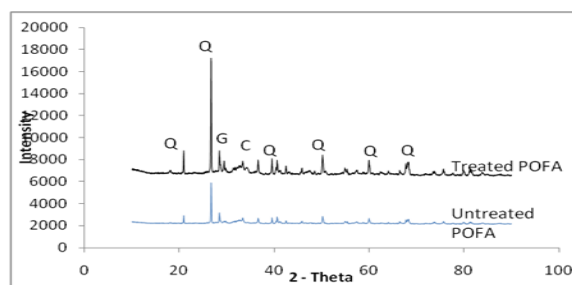

Figure 1 X-ray diffraction of POFA

As it can be seen from Figure 2, the scanning electron microscopy of the treated POFA is presented it has a porous cellular. Figure 3 shows the picture of treated POFA while Figure 4 shows untreated POFA. The difference can be seen clearly as the treated POFA looks light gray because of the silica content while the untreated one looks dark because of low silica content.
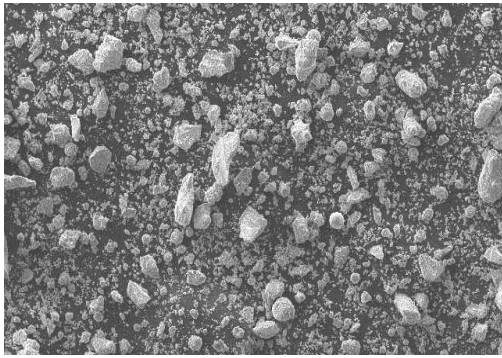
Figure 2 FESEM micrographs of POFA

Figure 3 Treated POFA

Figure 4 Untreated POFA

The result of volume shrinkage versus treated POFA is presented in Figure 5. The result shows that the shrinkage was least at the 2 wt% addition of treated POFA with a approximate value of 18%, as the addition of treated POFA increases between 2 wt% and 10 wt%. The shrinkage in this type of triaxial system was due to removal of residual amount of water from clay, decomposition of binder, liquid formation from the flux as well as generation of crystalline phases from amorphous materials such as treated POFA. From the physical appearance of the fired samples, no distortion or sagging was observed. The formation of glass and simultaneous dissolution and subsequent repre-cipitation of crystalline phases are the main controlling factors leading to shrinkage and expansion. The extent of primary reactions amongst the different ingredients was indicated by the first inflection point, i.e. shrinkage maxima [17]. The general trend of interaction remained more or less same at all compositions, only the magnitude differed. This type of interaction is a case of viscous composite sintering which involves much larger liquid contents than liquid phase sintering.
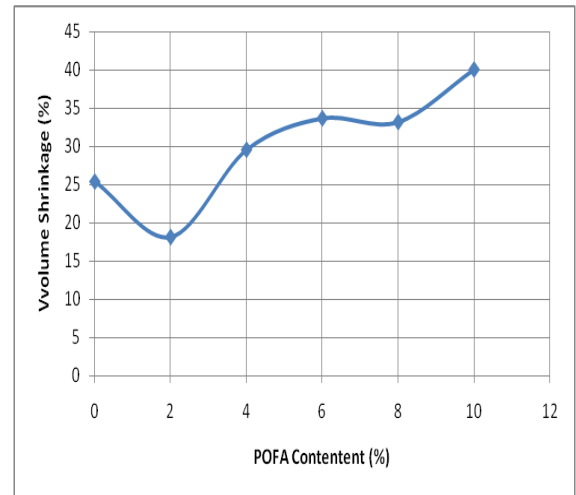

Figure 5 Volume shrinkage Vs POFA content

From Figure 6 it is apparent that porosity decreases with increasing treated POFA except for 2 wt% addition of treated POFA. The decrease could be due to the formation of a glassy phase that is mainly originated from the feldspar. Increasing treated POFA cause both an increase in the liquid phase amount and a decrease in liquid phase viscosity. Under the surface energy forces created by the fine pores contained in the ceramic body, the liquid phase tends to approach the particles and, therefore, open porosity decreases [19].
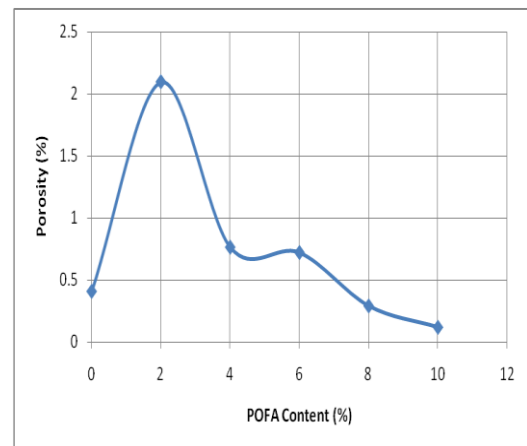

Figure 6 Porosity Vs POFA Content

From Figure 7, the bulk density for each composition shows the positive and almost a linear relation with the increment in addition of treated POFA except at addition of 10 wt% treated POFA. The highest value of bulk density occurs at the 8 wt% addition of the POFA with a value of 2.17 g/cm^3. In contrast, control sample (0 wt% addition of treated POFA) which has the lowest bulk density, approximately 1.55 g/cm^3. Similar results were obtained by Salem [19]. The high content of treated POFA in the composition contributes to the higher bulk density values. This could be due to decrease in internal pores as the addition of treated POFA increases which causes the densification to increase

as a result of wetting of crystalline phases by the lower amount of liquid phase formed, the quartz start to dissolute rapidly and produces more SiO_2 content to assist feldspar in dissolving the particles in porcelain and POFA [20].
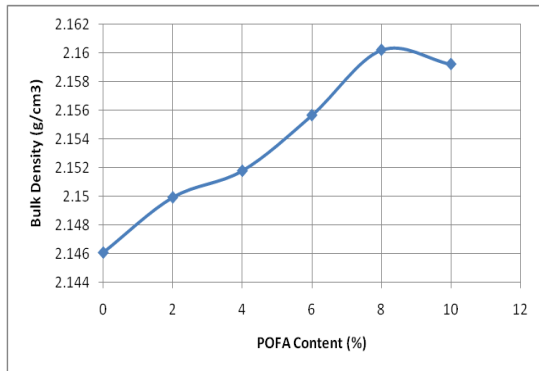

Figure 7 Bulk density Vs POFA content

Variation of flexural strength with treated POFA is shown in Figure 8. From the Figure it is revealed that bending strength showed maximum strength at 8 wt%. Further addition of treated POFA causes decrease in the bending strength. The increase may be due to the melting of quartz grain which contributes to the formation of homogeneous vitreous matrix, so the bending strength increases with the increase in treated POFA addition and as sintering continues [17, 21]. The decrease in bending strength occurs with the addition beyond 8 wt% of treated POFA. This phenomenon may be related to the formation of more glassy phase which probably affect the proper interlocking of mullite needles.

Figure 9 shows the compressive strength of the pellets sintered at a temperature of 1200°C. The compressive strength of porcelain bodies increased with an increase in POFA addition, and reached maximum values of about 70 MPa at 8 wt%. As the addition, of treated POFA continues that is above 8 wt% the compressive strength (Figure 9) decreased with both corresponding microstructural changes, mainly caused by porosity developments, as examined in FESEM Figure 10-13 studies and decrease in bulk density.
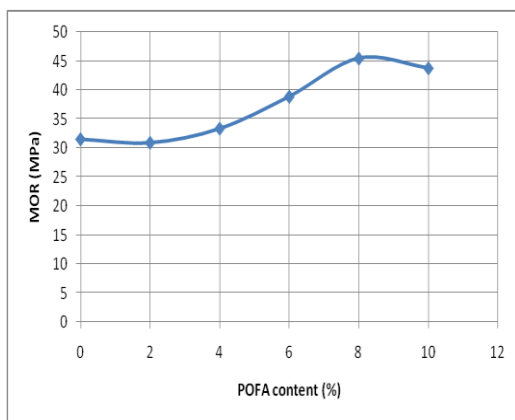

Figure 8 MOR Vs POFA content

Theoretically, in porcelain bodies, the thermal expansion coefficients of the glass matrix rarely match those of the dispersed particles; hence, there is always a strengthening effect because of

matrix reinforcement. Furthermore, interlocking mullite needles are always formed because of the firing temperature and kinetics [22]. Hence, the addition of POFA contributed to the quartz dissolution and produces more SiO_2 content that assisted feldspar in dissolving the particles in porcelain to the enrich the matrix reinforcement.
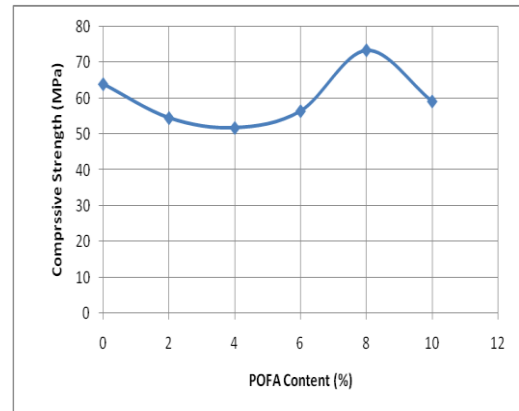

Figure 9 Compressive Strength Vs POFA Content

The XRD curves of samples are shown in Figure 10. The major crystalline phases identified are quartz and mullite in all the body mixes. Quartz peak increases with an increase in the addition of treated POFA. Between 8 wt% and 10 wt% addition of treated POFA there is not much difference in the peak this confirms the result from compressive strength.

Figure 11 shows the sintered control sample it can be seen the existence of pores. With the addition of 4 wt% of POFA densification becomes manifested. The pores becomes smaller as can be seen from Figure 12. As the addition of treated POFA increases to 8 wt% densification is highest and pores are the least. With the 10 wt% addition of treated POFA cracks were developed as can be seen from Figure 14. This confirms the result obtained from bulk density, bending strength and the compressive strength.
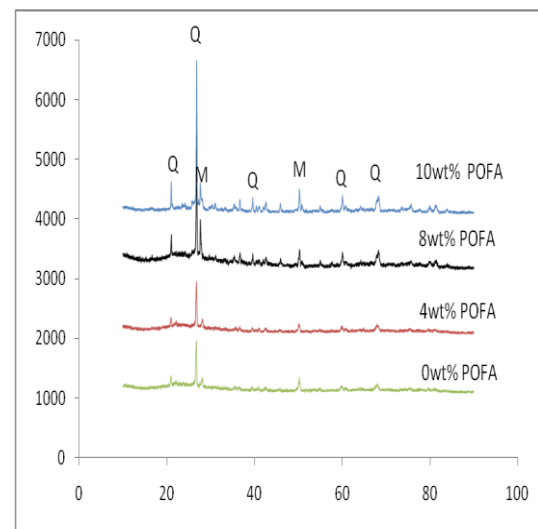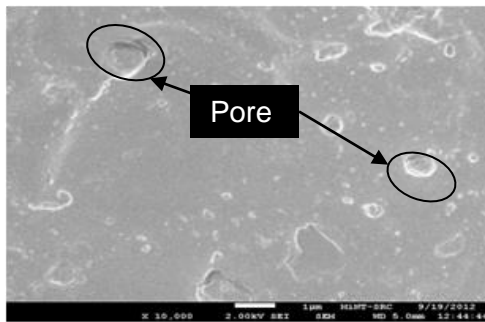

Figure10 XRD curves of sintered mixes
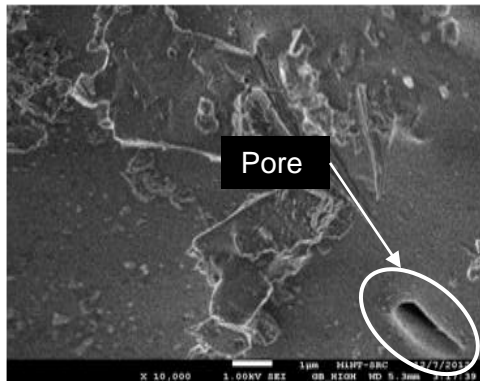
Figure 11 FESEM of control sample

Figure 12 FESEM of sample containing 4 wt% of POFA

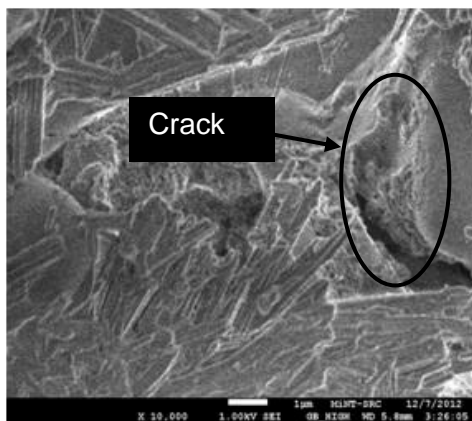**Figure 13** FESEM of sample containing 8 wt% of POFA

Figure 14 FESEM of sample containing 10 wt% of POFA

■**4.0 CONCLUSION**

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

The maximum strength for porcelain containing POFA occurred at 8 wt% addition of POFA. The results obtained from bulk density, and the microstructure studies are in conformity with the above. Porcelain containing POFA has about 7% weight reduction compared with normal porcelain.

References

[1] Malaysian Palm Oil Board (MPOB). 2010 Economic and statistic;http://econ.mpob.gov.my/economy/Overview_2009.pdf [accessed 11.08. 2012].
[2] Basri, H. B., M. A. Mannan, and M. F. M. Zain. 1999. Concrete using Waste Oil Palm Shells as Aggregate. *Cement and Concrete Research.* 29(4): 619–622.
[3] Awal, A. S. M., and M. Warid Hussin. 1997. The Effectiveness of Palm Oil Fuel Ash in Preventing Expansion Due to Alkali-Silica Reaction. *Cement and Concrete Composites.* 19(4): 367–372.
[4] Chindaprasirt, P., S. Homwuttiwong, and C. Jaturapitakkul. 2007. Strength and Water Permeability of Concrete Containing Palm Oil Fuel Ash and Rice Husk–Bark Ash. *Construction and Building Materials.* 21(7): 1492–1499.
[5] Tangchirapat, W., T. Saeting, C. Jaturapitakkul, K. Kiattikomol, and A. Siripanichgorn. 2007. Use of Waste Ash from Palm Oil Industry in Concrete. *Waste Management.* 27(1), 81–88.
[6] Chindaprasirt, P., S. Rukzon, and V. Sirivivatnanon. 2008. Resistance to Chloride Penetration of Blended Portland Cement Mortar Containing Palm Oil Fuel Ash, Rice Husk Ash and Fly Ash. *Construction and Building Materials.* 22(5): 932–938.
[7] Chandara, Chea, *et al.* 2012. Heat of Hydration Of Blended Cement Containing Treated Ground Palm Oil Fuel Ash. *Construction and Building Materials.* 27(1): 78–81.
[8] Kingery, W. D. 1976. *Introduction to Ceramics*. New York: Wiley. 78: 532.
[9] De Noni, Agenor, *et al.* 2010. Influence of Composition on Mechanical Behaviour of Porcelain Tile. Part I: Microstructural Characterization and Developed Phases After Firing. *Materials Science and Engineering*: A 527(7): 1730–1735.
[10] Das, Swapan Kr, and Kausik Dana. 2003. Differences in Densification Behaviour of K-And Na-Feldspar-Containing Porcelain Bodies. *Thermochimica Acta.* 406(1): 199–206.
[11] Prasad, C. S., Kedar Nath Maiti, and R. Venugopal. 2003. Effect of Substitution of Quartz by Rice Husk Ash and Silica Fume on the Properties of Whiteware Compositions. *Ceramics international.* 29(8): 907–914.
[12] Maity, S., and B. K. Sarka, 1996. Development of High-Strength *Whiteware Bodies*. 2219(96).
[13] Dana, K., J. Dey, and S. K. Das. 2005 Synergistic Effect of Fly Ash and Blast Furnace Slag on the Mechanical Strength of Traditional Porcelain Tiles. *Ceramics international.* 31(1): 147–152.
[14] Prasad, C. S., K. N. Maiti, and R. Venugopal. 1991. Replacement of Quartz and Potash Feldspar with Sericitic Pyrophyllite in Whiteware Com-Position. *Interceram.* 40(2): 94–98.
[15] Prasad, C. S., K. N. Maiti, and R. Venugopal. 1997. Thermal Behaviour of Whiteware Bodies Containing Sericitic Pyrophyllite. *Interceram* 46(3): 154–161.
[16] Schuller, K. H. 1964. Reactions Between Mullite and Glassy in Porcelain. *Trans. J. Brit. Ceram. Soc.* 103(63): 1964.

[17] Yilmaz, Handan, *et al.* 2011. Effect of Fatigue on Biaxial Flexural Strength of Bilayered Porcelain/Zirconia (Y-TZP) Dental Ceramics. *Dental Materials.* 27(8): 786–795

[18] Martín-Márquez, J., J. M., Rincón, and M. Romero. 2008. Effect of Firing Temperature on Sintering of Porcelain Stoneware Tiles. *Ceramics International*. 34(8): 1867–1873.

[19] Salem, A., S. H., Jazayeri, E., Rastelli, and G. Timellini. 2010. Kinetic Model for Isothermal Sintering of Porcelain Stoneware Body in Presence of Nepheline Syenite. *Thermochimica Acta*. 503: 1–7.

[20] Kitouni, S., and A. Harabi, 2011. Sintering and Mechanical Properties of Porcelains Prepared from Algerian Raw Materials. *Cerâmica*. 57(344): 453–460.

[21] Ece, O. I., & Nakagawa, Z. E. 2002. Bending Strength of Porcelains. *Ceramics International*. 28(2): 131–140.

[22] Carty, William M., and Udayan Senapati.1998. Porcelain—raw Materials, Processing, Phase Evolution, and Mechanical Behavior. *Journal of the American Ceramic Society*. 81(1): 3–20.