Original Research Article

Nigerian Journal of Biotechnology and Life Sciences
ISSN: 2814-0281
Vol. 3 No 2c (2026) p. 670 - 677
http://www.njbls.fud.edu.ng/

An Innovative Construction and Production Method of Brick Interlocking System using Palm Oil Fuel Ash (POFA) as Cement Replacement

Z. I Takai, M. A. Ahmad, M. B Isa, F. M Umar

Department of Physics, Faculty of Science Northwest University, Kano

*Corresponding Author: zitakai21@gmail.com

https://doi.org/10.67601/njbls.v3i2c.149

Article info
Date received
17/08/2026
Date accepted
27/09/2026
Available online
30/09/2026

Keywords
Bric interlocking, Ordinary Portland cement (OPC), Palm Oil Fuel Ash (POFA), compressive strength, Porcelain

Abstract

To offer clean environments and affordable materials that reduce the cost of living is one of the objectives of sustainable development goals. Civilisation and advancement in every field of life are what are needed for the 21st century. The renewable sources such as recycling of by-product will help in sanitary and reducing cost of living as well as environmental sanitary. The present research is aimed to use palm oil fuel ash (POFA) as an additive ingredient to the porcelain body to find out the effect of substituting this modified POFA with Porcelain. Also will decide which composition/element in the POFA contents is the most enhancing the strength of porcelain when added to it that will help in the production of interlock. This involves the experimental work such as volume shrinkage, porosity, bending and compressive strengths and supported with a theoretical aspect. The chemical composition of palm oil fuel ash (POFA), shown that the silica content (SiO_2) in POFA is much higher than in ordinary Portland cement (OPC). It may be helpful to have more SiO_2 to help the pozzolanic reaction. The calcium oxide (CaO) content of the POFA is however less than that of Ordinary Portland cement (OPC) and Loss on Ignition (LOI) value of the POFA is more than that Ordinary Portland cement (OPC) at 3.10%. The results of the chemical analysis show that POFA is good pozzolanic material and can be used as a cement replacing material for the production interlock.

Introduction

Palm oil mill industry (POMI) solid waste has been growing tremendously year by year. It was reported that the palm oil waste was producing four million tons per year in Malaysia only which is also generated near this amount in Nigeria as well. Therefore, to overcome this problem the solution is to reuse this waste product and produced new composites that are beneficiary to human development (Abdulkareem et al., (2014), Some of the potential contributors include Nigerian oil palm companies/industries which contribute more than half of the world's total palm oil production, and which are poised for sustained growth with expected rise in the global demand for vegetable oil (Abla et al., 2010). Hence, it leads to a large contribution to the nation's pollution problem of about 2.6 million tonnes of solid waste in the form of palm oil fuel ash (POFA) (Aginam, Chidolue, & Nwakire, 2013). Based on the statistics Nigeria provided important percentages of about 12.16 and 14.02 tons per hectare of fresh bunch in

Copyright: ©2026 the Author(s). Published by Federal University Dutse. This is an open-access article distributed under the terms of the Creative Commons Attribution 4.0 International License (CC BY 4.0).

2010 and 2011 respectively (Ahmad et al., 2005). Whereas according to Malaysian Palm Oil Board (MPOB) is about 20.18 and 19.2 tons per hectare of fresh fruit bunch were produced in the year 2010 and 2011 as well. These make the total production of 90,566,927 tons and 90,070,272 tons of fresh fruit bunch in the year 2020 and 2025 (Al-Hadithi, 2012).

Tay and Show estimated that 7 tons of fibres and approximately 25 tons of empty bunches was discarded from the mill industry per 100 tons of fresh fruit bunches processed (Al Bakri et al., 2012). This waste product created from the Palm Oil Industry resulted in criticism and complaint. However, due to increases in price of oil, it becomes costly and unreliable to continue with the diesel generators for power supply. The empty fruit bunches (EFB) of palm trees, shells and fibres were used extensively in this concern as a fuel to heat the steam for electricity generation and during the palm oil extraction process (Ananda et al., 2015). After combustion in the steam boiler, there is around 5% of ash called Palm Oil Fuel Ash (POFA), ing produced (Antoni et al., 2017). Hence, with the continuous increase in the production, more ash will be generated that causes potential environmental issue (Pollution) for disposing it as landfill material as it has limited utilization (Asadi et al., 2018).

These abundant agriculture and industrial wastes are always discharge from the industries; these wastes also include POFA can be reutilized as potential cement replacement materials especially in the concrete construction. Hence, the researchers will think of saving materials like cement, with the effective use of POFA as a cement replacement, and also to mitigate the pollution in the country. According to Md. The application of POFA as a cement replacement material in concrete is logical, worthy and justifiable as the concrete industry is facing the need to reduce the cost of concrete materials, and minimize waste disposal issues in the current times.

The recycling of these waste materials such as POFA and Ceramic Sludge (CS) is very useful, POFA as one of the pozzolanic materials that use for many applications such as cement replacement or even used as a renewable energy resources (Asadi et al., 2018). Pozzolanic materials are fine materials, which contain silica, alumina in higher amount and calcium oxide, iron oxide, magnesium oxide and alkalis in fewer amounts. Silicon oxide SiO_2 is a major composition of POFA, when silica and alumina react in the presence of calcium oxide (CaO_2) or calcium hydroxide $Ca(OH_2)$ they form cementitious materials which can be used as a cement replacement and can exhibit high strength concrete more than the normal cement.

The higher the fineness of POFA particles the higher the strength developed. As important indexes for exploring and promoting these technological and economic potential of the country's industrialization processes, the indigenously developed technology is also taken into account. It has been established that, these abundant raw materials are available for the manufacture of porcelain as well as heated ceramic wares in most of the tropical countries such as Nigeria (Babafemi et al., 2018).

Porcelain is a ceramic material made by heating raw materials; generally, consist of clay in the form of kaolin when heated in a kiln to temperatures between 1,200 and 1,400 degrees of Celsius. Glass and the mineral mullite are typically created in the fired body at these high temperatures, which is what gives porcelain its strength, toughness and translucence. The very high density, industrial fast firing cycle and tangible mechanical strength and wear resistance of porcelain had shown that it was veritable stoneware (Bahoria, 2013).

Other materials like rice husk ash and silica fume are being used to replace the quartz, and their mechanical properties are improving, others use kyanite, bauxite, fly ash, sericitic pyrophyllite and silliminite sand (Bai, Wild & Sabir 2003) as replacement material for quartz. The alumina also plays an important role in the mechanical properties of white ware because primary mullite is formed (Baid, & Bhole, 2013). The research reported by Parasad et al., (2003), show that rice husk ash with minor or negligible amount of carbon in cooperated in the white ware composition, makes an improvement in the properties of porcelain. Hence, the flabby natures of rice husk ash (RHA) particles which

unfavourably influenced the output of body preparation and possibly increase the loss caused by cracking and deformation. Hence, the present study is aimed at using the POFA as one of the additives ingredients in the porcelain body and understanding the effect of using the replacement of the modified POFA in the porcelain. Also to determine which composition/element in the POFA contents that most increases the strength of porcelain when added to it. This may involve the experimental work such as volume shrinkage, porosity, bending and compressive strengths and supported with a theoretical aspect**.**

Material and Method

Data Collection

The contents (waste product of palm oil nuts) used in this study was collected from the Palm Oil Mill industry assigned. The waste from that industry was in the form of ash, known as Palm Oil Fuel Ash (POFA) that was used during the course of the research work. The equipment and apparatus used are: Oven, Ball Mill Machine, Severs, Digital Balance BM Series H-8000 and Electric Furnace.

Experimental procedures

Sample Preparation

For 1 day (24 hrs) or more, the POFA was dried in an oven at 100 - 110 ºC. The sample were removed after being dried, and the particle size was reduced to an appropriate level, which is required to improve the reactivity, with the aid of ball mill machine. The milling time always was about an hour or one hour 30 minutes at 200 revolutions per second (r.p.m.). The sieving was performed after this grinding. The sample will be sieved in a less than 150 μm sever, so that those above this will be removed from the sample. The untreated POFA were fired alone to burn off the excess carbon residue on it. This can only be done when as we heated it to a temperature of about 600 ºC for 1.5 hours in an electric furnace.

In addition, the raw material powder of the Porcelain was also separately grounded in a ball mill, similar to POFA. The powder was sieved and dried using sieve shaker and an oven. The treated POFA was added as an ingredient to porcelain powder at the range of 2–10 wt%. A ball mill mixing for 1 hour 30 minutes was also performed to mix this composition. The mixed powder was pressed into pellets and bars at a pressure of around 90-95 MPa. We must ensure that all the pellets and bars was sintered at a temperature of about 1200 degree of Celsius for 2 hours soaking time, at a heating rate of 50 ºC per minute.

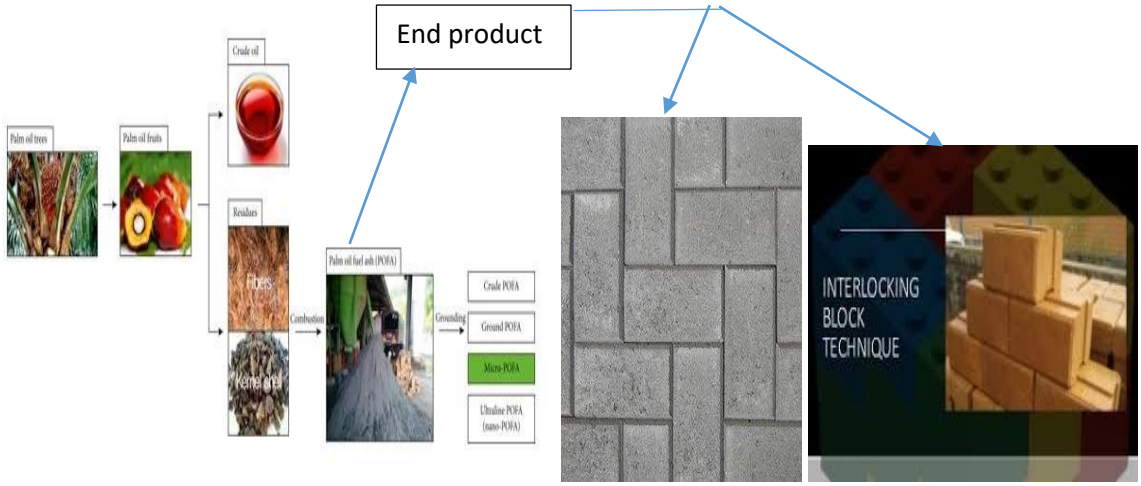


Figure 1: Graphical Abstract for Data collection

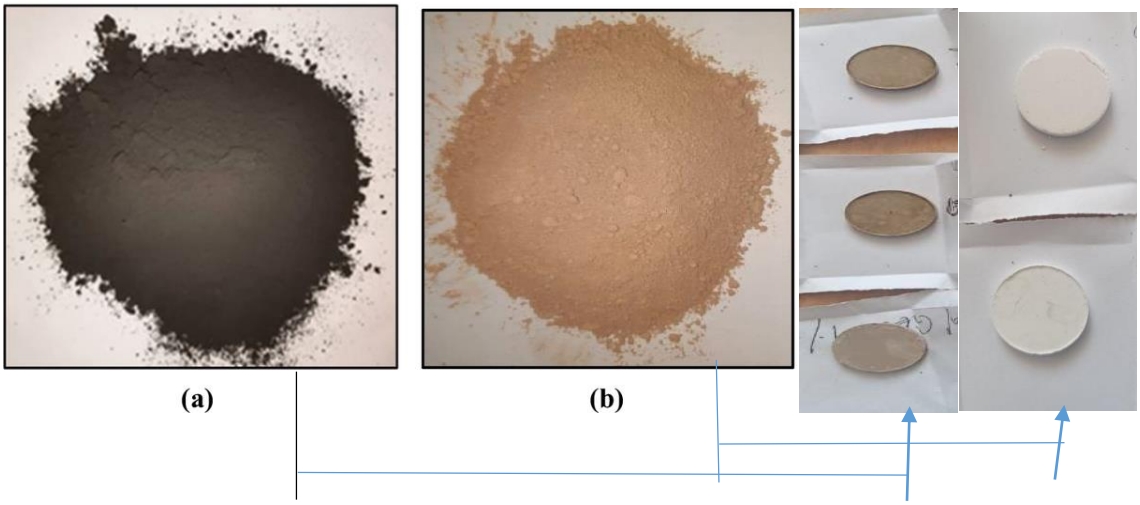


Figure 2: (a) Treated POFA furnace for 1.5h at 600 ºC (b) Prepared porcelain powder

Sample Analysis

The analysis involved an experimental procedure which was carried out in the laboratory. As this involved the sample preparation as mentioned above. Using this procedure, the physical and mechanical properties of the pellets such as volume shrinkage, porosity, bending strength, and compressive strength were also determined. The chemical composition of the treated POFA was investigated using X-Ray Fluorescence (XRF) while the crystalline structure of the treated POFA was determined through XRD and the microstructural features were examined using FESEM. Additionally, the prototype of the fabricated Brick Interlocking system is indicated in the figure 2 above.

Results and Discussion

X-ray fluorescence analysis

The chemical composition of treated POFA was analysed using X-ray fluorescence analysis (XRF), which was reported previously by (Oyeleke et al., 2011), (Abdul et al., 2011) and (Weerachart et al., 2009). 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 (SiO_2 58.37%), (C 9.74%), (CaO 3.65%), (K_2O 5.69%), (P_2O_5 3.27%), (Fe_2O_3 4.30%) and (Al_2O_3 4.26%) respectively.,

Table 1: Chemical Composition of treated POFA

Compound	Composition (wt %)
SiO_2	58.37
C	9.74
CaO	3.65
K_2O	5.69
$P2O_5$	3.27
Fe_2O_3	4.30
$Al2O_3$	4.26
Cl	6.31
MgO	1.34
SO_3	1.59
LOI	1.46

XRD analysis

The X-ray diffraction analysis was used to study the structural properties of the composition materials and the result is presented in the Figure 3. It has been observed that the X-ray diffraction (XRD) pattern of the samples containing three different of palm oil fuel ash (POFA), porcelain and mixture of POFA and Porcelain with sintering temperature of 1100 °C. This sintering temperature was specifically selected to ascertain the reason behind maximum compressive strength on this temperature. From the figure, it is clear that, the mineralogical phases of the samples are visibly seen. The result further

revealed that the quartz as the major identified phases and also mullite can easily be seen from the XRD analysis. The peak of quartz decreases as the percentage of POFA increases, and the formation of mullite increases as the quartz decreased, as reported by Balaban (2012) the mechanism behind the mullite growth was believed to be due to atmosphere induced changes to the composition in the oxidising atmosphere that facilitate mass transport and crystal growth. Therefore, in a pure porcelain the highest compressive strength was achieved. The presence of SiO_2 and Al_2O_3 helped in mullitization of the crystal. The increment of the mullite is due to the melting of quartz grain which contributes to the formation of a homogeneous vitreous matrix Barbhuiya, Chow, & Memon, (2015). According to Chaudhuri, mullite formation took place as a result of replacement of Al^{+3} in the porcelain structure owing to the role played by Fe^{+3} and Ti^{+4} that are refereed to foreign ions Batayneh, Marie, & Asi, (2008). Since these foreign ions were found in the POFA, thus it helps in the formation of mullite as the POFA materials.

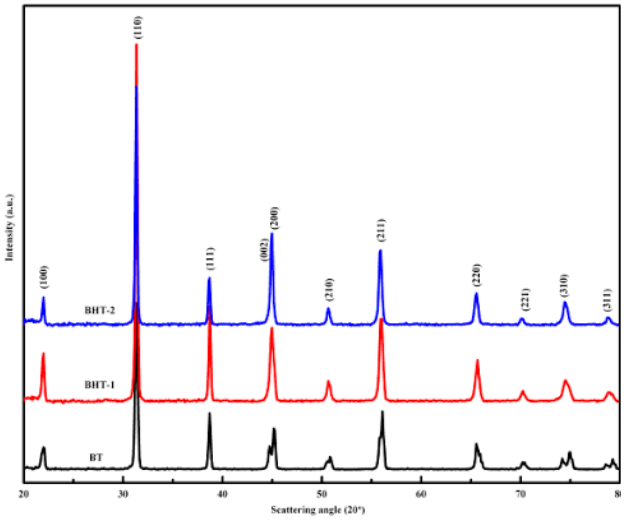


Figure 3: XRD pattern of three compositions of POFA, Porcelain and their combination sintering at temperature of 1100°C.

FESEM analysis

The morphological study of the samples has been investigated by using Scanning Electron Microscope (SEM) and the result is revealed in Figure 4, which indicated the present of POFA, Porcelain and the combined mixture, are shown as indicated in Figure 4 (a,b & c), the mixture has the lowest porosity and hole around the surface due to the absence of POFA. In Figures 4 (b) and low contain of it in 4 (c), more porosity and hole around the surface due to the addition of POFA is pronounce 4 (c).

Mechanical Properties

Studies and industrial findings believed that the most significant factor that dictates mechanical properties of brick interlock is compressive strength of porcelain. The result of compressive strength of this research is presented in Figure 5. As seen it indicates that the compressive strength is increasing with the increase of annealing temperature from 0%, 92.05MPa to 1100 °C, 126.42MPa. The highest compressive strength for all the three sintering temperatures was obtained at 1100°C which is 126.42 MPa. However, the lowest values of compressive strength for all the three sintering temperatures was obtained at 1200°C sintering temperature which is 31.03 MPa at 100% of the replacement. These compounds would cause pores to begin at high temperature, and then decrease the strength of the final product, Bazaz, Khayati, & Akrami, (2006). Due to the reinforcement of matrix, the strengthening effect was observed, so it should be noted that it is hard to find out the matching of the coefficient of the dispersed particles with that of the cement matrix in porcelain body.

Likewise, the replacement of quartz by palm oil fuel ash (POFA) resulted in the reinforcement of the matrix structure in the porcelain body, while the dissolution of quartz affected by the increase in sintering temperature caused the overall formation of matrix structure. It is also worth noting that, if the SiO_2 content of the particles is low, the presence of the particles in the presence of feldspar also helps in the melting of other particles as observed by (Beata & Miera 2017). The graph of compressive strength against composition of palm oil fuel ash (POFA) is obtained as depicted in figure 5.

Conclusion

The results obtained in this research are successfully showing that palm oil fuel ash (POFA) is a sustainable material that can be used as an

additive and pozzolanic substitute in porcelain for the production of interlock. Chemical characterization showed that POFA contains a notably higher silica (SiO_2) content, lower calcium oxide (CaO) content and a Loss on Ignition (LOI) value of 3.10% compared to ordinary Portland cement (OPC).

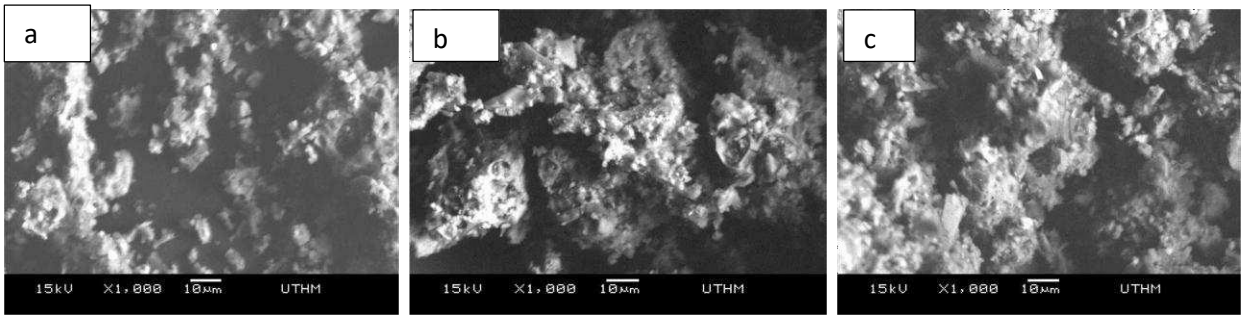


Figure 4: SEM micrographs of (a) POFA (b) Porcelain and (c) POFA/Porcelain

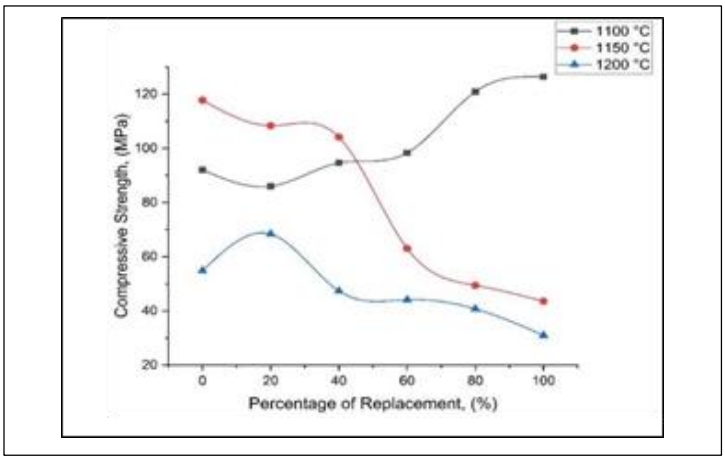


Figure 5: Graph of the compressive strength of porcelain against composition of palm oil fuel ash (POFA), Porcelain and the mixture of Porcelain/POFA at different sintering temperatures

The parameters of volume shrinkage, porosity and bending and compressive strength all validate the effectiveness of POFA as a pozzolanic material to improve the structural and mechanical properties of the brick interlocking system. Conclusively, the study falls under the Sustainable Development Goals (SDGs) as it converts agro-industrial waste into a resource. The adoption of POFA not only aligns with the circular economy's goal of minimizing environmental waste, but also offers a sustainable and cost-effective solution that helps cut production expenses and move towards 21st-century sustainable production.

Acknowledgments

This work was financially supported by Northwest University, Kano, Nigeria under Institutional Base Research Grand (IBR) funded by Tertiary Education Trust Fund (Tetfund). While preparation and characterization of the material was carryout at Microelectronic and Nanotechnology-Shamsuddin Research Centre (Mint-SRC) Universiti Tun Hussein Onn Malaysia (UTHM).

Author contribution

Z. I. Takai: Conceptualization, methodology, experimental design, and original draft preparation. M. A. Ahmad: Data curation, formal

analysis, and investigation of the saturable absorbers. M. B. I. Isa: Validation, visualization, and manuscript review & editing. F. M. Umar: Supervision, resources, project administration, and final review

Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

Abdulkareem, O. A., Al, A. M. M., Kamarudin, H., Nizar, I. K., & Saif, A. (2014). Effects of elevated temperatures on the thermal behavior and mechanical performance of fly ash geopolymer paste , mortar and lightweight concrete. *Construction and Building Materials*, *50*, 377–387. https://doi.org/10.1016/j.conbuildmat.2013.09.047

Abla Mecif,z Julien Soro,y Abdelhamid Harabi,w, z and J. P. B. (2010). Preparation of Mullite- and Zircon-Based Ceramics Using Kaolinite and Zirconium Oxide: A Sintering Study. *Journal the American Ceramic Society*, *1312*(26387), 1306–1312. https://doi.org/10.1111/j.1551-2916.2009.03595.x

Aginam, C. H. Chidolue, C. A., & , And Nwakire, C. (2013). Investigating the Effects of Coarse Aggregate Types on The Compressive Strength Of Concrete. *International Journal of Engineering Research and Applications*, *3*(4), 1140–1144.

Ahmad, S., Nawaz, M., & Elahi, A. (2005). Effect of superplasticizers on workability and strength of concrete. *Journal of Concrete & Structures*, *324*(3), 23–24.

Al-Hadithi, A. I. (2012). Behaviour of Reinforced Polymer Modified High Strength Concrete Slabs under Low Velocity Impact. *Anbar Journal for Engineering Sciences*, *9*(1), 171–189. https://doi.org/10.37650/ijce.2013.80395

Al Bakri A. Mohd Mustafa, Kamarudin Hussin, Che Mohd Ruzaidi, S. B., & Rozaimah Ramly, N. K. N. (2012). Behavior of Reinforced Polymer Modified High Strength Concrete Slabs under Low Velocity Impact. *School of Materials Engineering*, *6*, 2012.

Ananda Ramakrishna, K., Sateesh Babu, K., Guravaiah, T., Naveen, N., & Sk, J. (2015). Effect of waste ceramic tiles in partial replacement of coarse and fine aggregate of concrete. *International Advanced Research Journal of Science, Engineering and Technology*, *2*(6), 13–16.

Antoni, Halim, J. G., Kusuma, O. C., & Hardjito, D. (2017). Optimizing Polycarboxylate Based Superplasticizer Dosage with Different Cement Type. *Procedia Engineering*, *171*, 752–759. https://doi.org/10.1016/j.proeng.2017.01.442

Asadi, I., Sha, P., Fitri, Z., & Abu, B. (2018). Thermal conductivity of concrete – A review. *Journal of Building Engineering*, *20*(8), 81–93.

Asadi, I., Shafigh, P., Bin, Z. F., Hassan, A., & Mahyuddin, N. B. (2018). Author ' s Accepted Manuscript Thermal conductivity of concrete - A review Reference : *Journal of Building Engineering*. https://doi.org/10.1016/j.jobe.2018.07.002

Babafemi, A. J., Šavija, B., & Paul, S. C. (2018). Engineering Properties of Concrete with Waste Recycled Plastic : A Review. *Sustainability*, *3875*(10), 1–26.

Bahoria, P. and N. (2013). Replacement of natural sand in concrete by waste products: a state of art. *Journal of Environmental Research And Development*, *7*(4), 1651–1655.

Bai, J., Wild, S., & Sabir, B. B. (2003). Chloride ingress and strength loss in concrete with different PC – PFA – MK binder compositions exposed to synthetic seawater. *Cement and Concrete Research*, *33*(8), 353–362. https://doi.org/10.1016/S0008-8846(02)00961-4

Baid, A. S., & Bhole, P. S. D. (2013). Effect of Micro-Silica on Mechanical Properties of Concrete. *International Journal of Engineering Research & Technology*, *2*(8), 230–238.

Balaban, O. (2012). The negative effects of construction boom on urban planning and environment in Turkey : Unraveling the role of

the public sector. *Habitat International*, *36*(1), 26–35.

Barbhuiya, S., Chow, P., & Memon, S. (2015). Microstructure , hydration and nanomechanical properties of concrete containing metakaolin. *Construction & Building Materials*, *95*, 696–702.

Batayneh, M. K., Marie, I., & Asi, I. (2008). Promoting the use of crumb rubber concrete in developing countries. *Waste Management*, *28*, 2171–2176. https://doi.org/10.1016/j.wasman.2007.09.035

Bažant, Z. P., Kaplan, M. F., & Bazan t, Z. P. (1996). *Concrete at high temperatures: material properties and mathematical models. London: Addison-Wesley*. London: Addison-Wesley.

Bazaz, J. B., Khayati, M., & Akrami, N. (2006). Performance of concrete produced with crushed bricks as the coarse and fine aggregate. *Construction and Building Materials*, *616*(8), 1–10.

Beata Łaźniewska-Piekarczyk, Patrycja Miera, J. S. (2017). Plasticizer and Superplasticizer Compatibility with Cement with Synthetic and Natural Air-Entraining Admixtures. *IOP Conf. Series: Materials Science and Engineering*, *245*, 1–7. https://doi.org/10.1088/1757-899X/245/3/032094