Binary Blended Plantain Stalk Ash-Metakaolin as Source Materials for Sustainable Geopolymer Concrete

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Abstract: ***Concrete is one of the most extensively used construction material in the world. The research aims at examining the potential use of bio-ash derived from plantain stalks biomass as sustainable material in the production of geopolymer concrete. Large quantity of the first source material was collected from the dump site of a segment of the Kaduna Central market designated for sales of all kinds of fruits. At the onset, biomass was collected and transported to the Civil Engineering Laboratory, Kaduna Polytechnic, thereafter, sundried and burnt into ashes in a fabricated steel rotary kiln. The burnt ash was then pulverised with a ball milling machine. A second source material used was metakaolin derived from is industrial kaolin subjected to elevated temperature of 750 ^oC in a furnace and at retention time of 1 hr. For material characterisation, series of physicochemical tests were performed on several aliquots obtained from both materials. Tests performed include, visual inspection, particle density, LOI, scanned particle morphology, types and quantity of metal oxide via X-Ray Fluorescence, mineral composition via X-Ray diffractometer, FTIR and determination of pH. Geological mineral aggregates used include oven dried mass of fine river sand, quarry dust and gravels as coarse aggregate are combined either in fine-to-coarse ratio of 1: 1 (1000 g: 1000 g) or river sand - to-quarry dust-to-coarse grave ratio of 1: 1: 2 (500 g: 500 g: 1000 g). For production of the geopolymer concrete, alkaline liquid prepared from a combination of NaOH and Na_2SiO_3 at a concentration of 12 M. Also, ratio of the activator solution-to-(PPSA + MK) by dry mass was maintained at 0.4 throughout the research. The designed aggregates were mixed with the prepared geopolymer binder; the aggregates formed about 75% of the entire mixture by mass, which was adapted for the research. In its fresh state, the mixture was poured into the 5 fabricated steel moulds (70 mm x 70 mm x 70 mm), vibrated on vibrator table, air cured for 24 hrs under transparent low density polythene, then steam cured at varying steam temperature of 60 ^oC or 90^oC. Finally, series of crushing strength tests were carried out on all the 110 test cubes on completion of the recommended 28 day air-cured. Test trend obtained from the three experimental hypotheses put forward indicate that, as the mixing duration increases from 2 to 10 day (stepwise of 2), the average compressive strength increase from 15.45 N/mm^2 to 22.15 N/mm^2, when steam-cured at 60 ^oC, as against 19.78 N/mm^2 to 28.21 N/mm^2, steam9cured at 90 ^oC. The effect of variation in the duration steam-cure at varying temperature showed average compressive strength of 9.10 N/mm^2 (for the control cubes) to 35.81 N/mm^2 steam-cured at 60 ^oC. Whereas, average compressive strength of 9.53 N/mm^2 was obtained for control specimen. This later increased to 38.81 N/mm^2 at 5 day subjected to 90 ^oC steam-curing temperature. The proposed blended kaolin-PPSA source material has been proven to be a promising alternative matrix in the production of sustainable geopolymer concrete.***

Keywords: Geopolymer binder, Plantain Stalk, Metakaolin, Physicochemical tests

1.Introduction

Concrete is one of the most extensively consumed construction materials worldwide (Shi et al., 2011, Oyeleke, 2014). The binder in concrete is usually ordinary Portland cement (OPC). It has been estimated globally that, the construction sector produce approximately 12 billion tonnes of concrete, yearly; about 1.6 billion tonnes of Portland cement (PC) binder is utilised (Shi et al., 2011). The production of cement is not sustainable, as significant amount of mined limestone and other virgin natural resources goes into it (Senthamarai et al., 2010), coupled with the anthropogenic activities that goes with it (Bijen, 1996).

Researchers on sustainable environment have shown that the production of one tonne of cement launches approximately equivalent quantity of CO2 into the atmosphere (Shi et al., 2011, Jaturapitakkul et al., 2011, Anjan, 2011). The emission of CO_2 has been confirmed responsible for greenhouse effect (Kim and Chae, 2016) and production of acid-rain (Kim and Chae, 2016). From the greenness concept point, cement production is highly energy-intensive (Hardjito and Rangan, 2005). Put together, production of cement is neither sustainable nor eco-friendly and at variance with the concepts and ideals of sustainable development.

An alternative sustainable and eco-friendly binder in concrete technology has been proposed and elaborated (Davidovits, 1982, Davidovits, 1989, Davidovits, 1999). The researcher established alkaline-based activator as a special binding agent and coined it as geopolymer binder. According to him, geopolymer binder may be produced by a polymeric reaction of alkaline aqueous solution with silicon and aluminium minerals present in any sourced material. The researcher also suggested that any geological origin material such as metakaolin (Pan and Sanjayan, 2012), or natural zeolite (Perraki et al., 2003) consisting of silicon (Si) and aluminium (Al) based metal oxides in its composition, in amorphous state will as well be suitable for production of geopolymer binder.

Again, several industrial solid wastes such as, coal combustion ashes (Stefanović et al., 2011, Songpiriyakij et al., 2010), metallurgical slag (Hu et al., 2008), have also been used as source materials in geopolymer concrete technology. In addition, a combination of calcined and non-calcined minerals (Sakulich, 2011), combination of fly ash and metakaolin (Bell & Kriven, 2009), and combination of granulated blast furnace slag with MK (Pacheco et al., 2011) have been studied as suitable candidates materials as geopolymer binders.

Geopolymer cementitious medium may as well be produced through polymeric reaction of alkaline liquids and pozzolanic compounds (Si and Al) present in ashes obtained from crops and agro-industrial based biomass-residues such as rice husk ash, RHA (Chatveera and Lertwattanaruk, 2011, Tuan et al., 2011), and palm oil fuel ash (POFA) (Chindaprasirt et al., 2011). About a decade, Ismail et al. (2013) elaborated on production of geopolymer binder from binary powdery materials of POFA and MK. The use of biomass solid waste as start material to produce ash-based geopolymer binder has been a subject of increasing interest (Songpiriyakij et al., 2010, Wongpa et al., 2010 & Shi et al., 2011). So far reviewed, the application of ash derived specifically from Burnt Plantain Stalks (BPSA) biomass as potent source material for geopolymer binder has not been documented. It is hoped that the uniqueness of this innovative research will carve out a niche and in the mind of like researchers.

2.Review of Related Work

Nigeria is one of the 54 African countries, in West Africa; the country is blessed with naturally productive and diverse sustainable ecosystems, including mangroves, rainforest, savanna, as well as wetlands (FAO, 2001). The present government has taken series of proactive steps in prioritising and improving productivity of a number of domestically and internationally focused crops, such as fruits and vegetables (Ariyo et al., 2013, Padam et al., 2013 and Amaya, 2018). Plantain (Musa paradisiaca L.) or cooking banana is a perennial herbaceous plant, 2 to 9 m tall, with an underground rhizome or corm. It originated in South India and moved to South East Africa, from where it spread to Central and West Africa (Ariyo et al., 2013 and Amaya, 2018). In Nigeria and most African countries, the fruit is roasted by the roadside on heated charcoal, usually as lunch. The fruit can also be fried when ripe as “dodo”; sometimes the unripe or slightly ripened plantain pulp can be fried in heated vegetable oil to obtain plantain chips known in Nigeria parlance as “pekere”. Plantain chips have been identified as the most popular plantain products in Nigeria (Ariyo et al., 2013 and Amaya, 2018). Annual harvest of fresh plantain crop in Nigeria is estimated at 1, 855, 000 metric tonnes (Ariyo et al., 2013 & Amaya, 2018). Plantain is produced in large quantities in Edo, Delta, Ogun and Ondo states. Other producing region are Rivers, Cross river, Imo, Anambra, Lagos, Kwara, Benue, Plateau, Kogi, Abia and Enugun states. Generally, fruit rinds and stalks from banana and plantain constitute major solid wastes generation from fruit cropping, transporting, handling, fruit marketing environment and domestic consumption in Nigeria.

In 1982, Davidovits proposed that an alkaline liquid could be used to react with the silcon (Si) and the aluminium (Al) present in a source material of geological origin or in by-product materials such as fly ash (FA), and rice husk ash (RHS) to produce concrete binders. Because the chemical reaction that takes place is a polymerisation process. Davidovits (1989 & 1999) coined the term ‘Geopolymer’ to represent these binders. Geopolymers are members of the family of inorganic polymers. The chemical composition of the geopolymer material is similar to natural zeolite (but inorganic) materials, but the microstructure is amorphous instead of crystalline (Palomo et al., 1999; Xu and van Deventer 2000). The polymerisation process involves a substantially fast chemical reaction under ambient temperature and alkaline aqueous environment on Si-Al minerals. The end result is a three-dimensional polymeric chain and ring structure consisting of Si-O-Al-O bonds, as follows (Davidovits, 1999).

Most of the reported works to date on geopolymer materials were related to the properties of geopolymer paste or mortar (Johari et. al., 2011). Palomo et. al., (1999) studied the polymerization of low-calcium ASTM Class F fly ash at a molar Si/Al of 1.81. They used four different solutions with the solution-to-fly ash ratio by mass ranged from 0.25 to 0.30. Also, the molar SiO_2/K_2O or SiO_2/Na_2O of the solutions ranged from of 0.63 to 1.23. Each specimen was 10 ×10×60 mm in size. Interestingly, the best compressive strength obtained was more than 60 MPa for mixtures that used a combination of sodium hydroxide and sodium silicate solution, after curing the specimens for 24 hrs at 65 °C.

The two variables, curing temperature and curing time have been reported to play important role in determining the engineering properties of the geopolymer products made from by-product materials such as fly ash (Palomo et al., 1999). A wide range of temperatures and curing periods has been studied, ranging from room temperature to about 90 °C, and from 1 hr to more than 24 hrs. Geopolymers produced by using MK have also been reported to set at ambient temperature in a short time (Davidovits 1999). Barbosa et al., (2000) elaborated the process of manufacturing geopolymers by allowing the fresh mixtures to polymerize at room temperature for 60 mins, followed by curing at 65 °C for 90 mins, and subsequent drying at 65 °C.

Several factors have been identified and reported as important parameters influencing the properties of geopolymers (Palomo et al., 1999; Liew, et al., 2012 & Abdeldjouad et al., 2019). Specifically, Palomo et al., (1999) concluded curing temperature was a reaction accelerator in fly ash-based geopolymers, and significantly affects the mechanical strength. In addition to that, the type of alkaline liquid, and time dependent variables such as curing time, and subsequent drying time also affect the engineering properties. Higher curing temperature and longer curing time have been proven to result in higher compressive strength (Ismail and Muhammad, 2011).

Earlier, Balaguru et al., (1997) documented the use of geopolymer composites in strengthen reinforced concrete beams as well as geopolymer coating to protect the transportation infrastructures. Using geopolymer with the Si/Al ratio of more than 30, the researchers found that the performance of material produced was better than the organic polymers in terms of fire resistance, durability under ultra violet light, and did not involve any toxic substances.

Interesting researches have also shown that any material that contains mostly Silicon (Si) and Aluminium (Al) in its amorphous or glassy micro structural form may suffice as source in geopolymer technology. In view of the aforementioned, bio-ash produced from the stalk of plantain (Musa paradisiaca L.) under controlled burning environment may perhaps suffice.

3.Materials and Experimental Setup

3.1. Materials

Large quantity of Fresh Plantain Stalks (FPS) was sourced at zero costfrom a temporary dump site, located within the fruit section of the Kaduna Central Market, Kaduna North Local Government Area, Kaduna State, Nigeria, and then transported to the Civil Engineering laboratory, Kaduna Polytechnic, where they were beneficiated. The beneficiating process include, sun dried at an average temperature of 30^{o}C, within a span 4 months. The dried plantain stalks were subjected to burning in batches of 3.0 $\pm$ 0.2 kg, in a steel rotary kiln and stored. Also, the industrial kaolin used was calcined into metakaolin (MK) in an ELE-electric muffle CARBOLITE furnace. About 25$\pm$0.001 g of each batch of the raw kaolin was poured into each of the crucibles used and gradually heated to an elevated temperature maintained at 750 ^{o}C and at a retention time of 1 hr.

The fine mineral aggregates used in the research were of two types: a) the river sand and b) quarry dust. The coarse aggregate used was obtained from crushed igneous rock. All of the aggregates were oven dried at 105 ^{o}C for 24 hrs prior to use for any experimental test.

A combination of Sodium-based compounds [(NaOH) + (Na_2SiO_3)] and Potassium-based compound [(KOH)] were chosen as source of the alkaline liquid used. Analytical grade in flaky form of the NaOH and pelletised form of KOH were used for the preparation of the alkaline solution. The specific gravity and percentage purity of analytical grade of both chemicals is 2.130/ 98% for NaOH and 2.120/ 98% for KOH. Both oxides were manufactured by Sigma-Aldrich Pty Ltd, Australia. The Na_2SiO_3, also of analytical grade, was manufactured by PQ Australia. The chemical composition of the sodium silicate was Na_2O_3 = 14.7%, SiO_2 = 29.4% and water content 55.9% by mass.

The two hydroxide compounds were separately dissolved in deionized water. The concentration of each solution was expressed and maintained at 12 Molar. Also, the ratio of activator solution (NaOH + KOH)-to-(PPSA + MK) by mass was also maintained at 0.4. Enough volume of the activator solution was prepared and stored in 20 liters plastic container, and used as the geopolymer binding medium. The ratio of activator solution-to-blended PPSA and MK as source material by dry mass was fixed at 0.45 all through the experiment.

3.2. Methods

3.2.1. Physicochemical analysis of the PPSA and MK

Physical tests conducted on the PPSA include Visual inspection, and particle density analysis. Chemical tests conducted include, the determination of LOI, and Unburnt Carbon Content (UCC). An ELE-electric muffle furnace SCALTEC was used to carry out the test. Energy Dispersive X-Ray Analyzer (EDX-JEOL JSM-6380LA) was used for the SEM analysis, while the determination of metal oxide was performed via EDXRF-Minipal 4 X-ray spectrometer-PW4030, in accordance with SESDPROC-107 test method and the elemental composition was manually calculated. Other chemical tests conducted include determination of mineral compositions, using Brucker D8 Advanced X-Ray Diffractometer (XRD) and determination of pH value, using a calibrated HACH Sension 1 digital bench-top pH meter (model 2 Star).

3.2.2. Pan mixing of geopolymer bindingmedium with combined aggregates and production of the geopolymer concrete

At the onset, the 3 aggregates sourced (fine river sand and quarry dust; and coarse aggregate) were oven dried and then combined homogeneously in the ratio of 1: 1: 2 (500 g: 500 g: 1000 g) by mass of river sand-to-quarry dust-to-coarse gravel, and was maintained all through. The size of the river sand and quarry dust used ranges from 1.18-to-150 μm. The average size of the coarse aggregate is 20 mm. Put together, the fine and coarse aggregates which formed about 75% of the entire mixture by mass was adapted all through the experiment. The mixing drum was powered immediately all materials were poured into it, in order to prevent its malfunction, which may prevent rotation of the dry aggregates. The content in the mixer was continuously mixed for 5 minutes and homogeneous mix obtained.

3.2.3: Cube casting, curing and compressive test of the geopolymer concrete

Adequate quantity of the fresh ash-based geopolymer concrete produced was scooped from the lot and gently poured and filled into the 5 fabricated steel moulds (70 mm x 70 mm x 70 mm). The moulds were placed on a flat surface 1270 mm x 620 mm Creteangly multi-flow vibrator table (Height from ground = 600 mm), operated on 2 parallel steel bars, (1260 mm x 50 mm x 20 mm) and well secured within a space of 310 mm. The steel bars have an operating screw bar (dia. = 30 mm, and height = 300 mm), screwed in order to fasten and hold each mould with content onto the table surface, while vibration progressed for a duration of 2 mins. Still in the mould, the fresh geopolymer concrete cubeswere covered with transparent low density polythene to prevent excessive evaporation. In this condition, the cubes were allowed to air cured at ambient temperature for 24 hrs, after which demould and directly transferred to a locally fabricated boiler and stream curing tank, subjected to varying steam temperature. The crushing strength test using YES 300 Compression Testing Machine, Shaoxing Henghu Instrument was conducted on the entire 110test cubes produced after completion of the recommended 28 days curing as recommended for OPC concrete.

3.2.4. Experimental Hypotheses and Test Parameters

The first test hypothesis was that, compressive strength increases with increase in mixing time, under continuous mixing operation. In this test, separate set of fresh geopolymer concrete material was prepared and mixed batch-wise at varying mixing time of 2, 4, 6, 8 and 10 minutes, then where also separately steam-cured at 60 °C and 90 °C respectively. A set of 5 cubes each were prepared under specific mixing time and were steam-cured for 2 days at60 °C and 90 °C. Put together, 50 cubes were cast for the continuous mixing time, where the hardened concrete cubes were tested for compressive strength at the expiration of 28 days in an oven-dried condition.

The second test hypothesis states that, compressive strength increases with increase in the days of steam-curing temptations at 60 °C and 90 °C. At the expiration of 24hrs air-curing, the cubes were demould and transferred to steam-curing tank. However, depending on the batch of geopolymer concrete production, the 2 levels of steam-curing temperatures of 60 °C and 90 °C presented in the previous subsection were also adapted, while the duration of curing age used are 1, 3.7, 9 and 12 days. Also, at the expiration of steam curing, each batch of the hardened concrete was dry-cured in oven environment for 28 days. At the onset of this experiment, control experiment (as batch No.1 for each curing temperature level was adopted as reference sample) was conducted, where 5 fresh geopolymer concrete were cast, air cure for 24 hrs, demould and immediately sent for dry curing (without subjecting to steam-cure) in the oven environment for 28 days. Put together, 50 cubes were produced for the continuous mixing at varying duration of steam-curing days, while 10 cubes for the hardened concrete produced. Finally, all the 60 cubes were tested for compressive strength at the expiration of 28-day oven-dried condition.

4.Result and Discussion

4.1 Effect of variation in continuous mixing time on compressive strength

Figure 4.1indicates multiple data points of the two sets of hardened geopolymer concrete cubes subjected to variation in continuous mixing time and at 2 extreme curing temperatures. As can be observed, the cubes prepared from continuous mixing of 2 minutes and later steam-cured at 60 °C and 90 °C respectively possessed 28-day average crushing strength of 15.45 N/mm^2 and 19.78 N/mm^2. These values respectively increased to 22.15 N/mm^2 and 28.21N/mm^{2}when their fresh mixes were continuously mixed of 10 mins. The plots indicate that an increase in crushing strength was experienced with increase in duration of continuous mixing in the mixer. Similar trend was presented by Silva de Vargas et al., (2011) and Davidovits (1999). In addition to that, the crushing strength also increases with increase in steam-cured temperature at a specific continuous mixing duration of interest. For instance, the average crushing strength of the hardened concrete cubes which were continuously mixed for at 6 minutes and later subjected to 60 °C steam-cured temperature stood at 21.95 N/mm^2. For the same mixing duration but were steam-cured at 90 °C stood at 28.21 N/mm^2. The results generally reflect that variation steam-cure temperature influenced the geopolymerisation reaction, which in turn significantly influenced crushing strength of hardened geopolymer concrete produced (Ismail et al., 2011). In general, the test trends of the two tests are similar; the compressive strength increases as the mixing duration increased and steam-cure temperature varies. The above test data show that the compressive strength of PPSA-MK based geopolymer concrete can be increased by an increase in the mixing time.

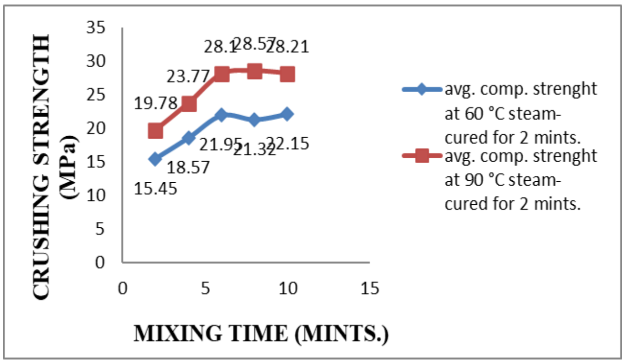

Figure 4.1: Effect of variation in continuous mixing time on compressive strength

4.2. Effect of variation in steam-curing days on compressive strength

Figure 4.2 indicates multiple data points of the two sets of hardened geopolymer concrete cubes subjected to variation in steam-curing days and at two extreme temperatures. As can be observed, the figure indicates that the average compressive strength obtained for the two sets of control specimen were respectively 9.10 N/mm^2 and 9.53N/mm^2 at control mixing time of2 minutes. However, the cubes that were steam-cured at 60 °C for a duration of 24 hrs (1day) possessed average crushing strength of 11.38N/mm^2 as compared to 14.38 N/mm^2 obtained for those steam-cured at 90 °C. In the same vein, the average compressive strength of cubes steam-cured at 60 °C for a duration of 12 days was 35.81N/mm^{2}when compared with an average compressive strength of 38.81 N/mm^2 for cubes steam-cured at 90 °C. Similar trend observed was presented by Davidovits (1999). In addition to that, the average crushing strength increases with increase in steam-cured temperature at a specified steam-curing day of interest. For instance, at 3 day steam-cure, the average compressive strength of 29.67 N/mm^2 was obtained at steam-cured temperature of 60 °C when compared with average compressive strength of 32.63 N/mm^2, when steam-cured temperature of 90 °C. In general, the test trends of the two tests were also similar; the compressive strength increases as the steam-curing duration increased. The above test data show that the compressive strength of PPSA-MK based geopolymer concrete can be increased by an increase in the steam-curing duration (Davidovits1999and Silva de Vargas et al., 2011).

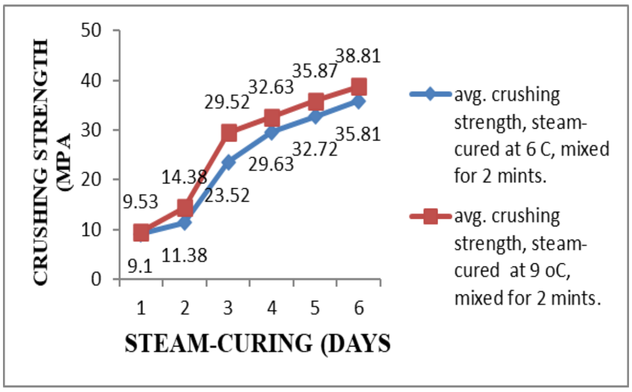

Figure 4.2: Effect of variation in steam-curing days on compressive strength

In summary, the compressive strength of the PPSA-MK based geopolymer concrete increased within the steam-curing duration and the steam-cured temperature explored.

5.Conclusion

Based on the experimental work on the tests on sourced materials and the geopolymer concrete produced, the following conclusions were drawn:

As the steam-curing temperature changes from 60 °C to 90 °C, the compressive strength of the PPSA-MK-based geopolymer concrete increases. Also, as the duration of steam-curing at a specific temperature of either 60 °C or 90 °C, increases and within the range of 1 day-to 12 days curing, the compressive strength of the PPSA-MK-based geopolymer concrete also increases.

The compressive strength of the PPSA-MK based geopolymer concrete increased by an increase in the mixing time.

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References

[1] Abdeldjouad, L., Asadi, A., Huat, B. B. K., Jaafar, M. S., Dheyab, W. & Elkhebu, A. G. (2019). Effect of curing temperature on the development of hard structure of alkali-activated soil. International Journal of GEOMATE.17 (60), 117-123.
[2] Anjan, K. C (2011). Chemistry and engineering of the clinkerization process-Incremental advances and lack of breakthroughs. Cement and Concrete Research. (41) 624-641.
[3] Amaya, N. (2018). The world's leading plantain producers. Retrieved May 12, 2019, from https://worldatlas. com/articles/the-world-s-leading-platain-producers. html.
[4] Ariyo, O. C., Ariyo, M. O., Okelola, O. E., Omodona, S. Akesode, H. A., & Akanni, R. J. (2013). Profitability analysis of plantain marketing in Kaduna metropolis, Kaduna state Nigeria. Journal of Agricultural and Social Research.13 (1), 21-30.
[5] Balaguru, P., Kurtz, J. & Rudolph, J. (1997). Geopolymer for repair and rehabilitation of reinforced concrete beams. St. Quentin, France, Geopolymer Institute: 5.
[6] Barbosa, V. F. F., MacKenzie, K. J. D. & Thaumaturgo, C. (2000). Synthesis and characterisation of materials based on inorganic polymers of alumina and silica: sodium polysialate polymers. International Journal of Inorganic Matter.2 (4), 309-317.
[7] Bijen, J. (1996). Benefits of slag and fly ash. Construction and Building Materials.10 (5), 309-314.
[8] Chatveera, B. & Lertwattanaruk, P. (2011). Durability of conventional concretes containing black rice husk ash. Journal of Environmental Management.92, 59-66.
[9] Chindaprasirt, P., Chotetanorm, C., and Rukzon, S. (2011). Use of palm oil fuel ash to improve chloride and corrosion resistance of high-strength and high-workability concrete. Journal of Materials in Civil Engineering.23 (4), 499-503.
[10] Davidovits, J. (1982). Mineral polymers and method of making them. Synthetic Minerals.4, 349-386.
[11] Davidovits, J. (1989). Geopolymers and geopolymeric new materials. Journal of Thermal Analysis.35 (2), 429-441.
[12] Davidovits, J. (1999). Geopolymers: inorganic polymeric new materials. Journal of Thermal Analysis.37 (8), 1633-1656.
[13] FAO, (2001). Online database of the Food and Agricultural Organization of the United Nations. Retrieved May 13, 2019, from https://apps. fao/default. html.
[14] Hardjito, D. & Rangan, B. V. (2005). Development and properties of low-calcium fly ash-based geopolymer concrete. Research Report GC 1, Curtin University of Technology Perth, Australia.
[15] Hu, S., Wang, H., Zhang, G. & Ding, Q. (2008). Bonding and abrasion resistance of geopolymeric repair material made with steel slag. Cement & Concrete Composites.30, 239-244.
[16] Ismail, M. E. & Muhammad, B. (2011). Influence of elevated temperatures on physical and compressive strength properties of concrete containing palm oil fuel ash. Construction and Building Materials.25, 2356-2364.
[17] Ismail, M., Yusuf, T. O., Noruzman, A. H. & Hassan, T. O. (2013). Early strength characteristics of palm oil fuel ash and metakaolin blended geopolymer mortar. Advance Materials Research.690, (1045-1048).
[18] Jaturapitakkul C., Tangpagasit J., Songmue, S. & Kiattikomol, K. (2011). Filler effect and pozzolanic reaction of ground palm oil fuel ash. Construction and Building Materials.25, 4287-4293.
[19] Joharis, M. A. M., Brooks, J. J., Kabir, S. & Rivard, P. (2011). Influence of cementitious materials on engineering properties of high strength concretes. Construction and Building Materials.25, 2639-2648.
[20] Kim, T. & Chae, C. U. (2016). Evaluation analysis of the Co_2 emission and adsorption life cycle for precast concrete in Korea. Sustainability.8, 663.

[21] Liew, Y. M., Kamarudin, H., Mustafa Al Bakri, A. M., Luqman, M., Khairul Nizar, I., and Ruzaidi, C. M. (2012). Processing and characterization of calcined kaolin cement powder. Construction and Building Materials.30, 794-802.
[22] Oyeleke, R. B., (2014). Potential of Kaolin-Palm Oil Fuel Ash Mixture as Sustainable Landfill Liner Material. PhD Thesis, Faculty of Civil Engineering, Universiti Teknologi Malaysia, Skudai, Johor, Malaysia.
[23] Pacheco-Torgal, F., Moura, D., Yining, D. & Jalali, S. (2011). Composition, strength and workability of alkali-activated metakaolin based mortars. Construction and Building Materials.25, 3732-3745.
[24] Padam, B. S., Tin, H. S., Chye, F. Y. & Abdullah, M. I. (2014). Banana by-products: an under-utilized renewable food biomass with great potential. Journal of Food Science Technology.51 (12), 3527-3545.
[25] Palomo, A., Grutzek, M. W. & Blanco, M. T. (1999). Alkali-activated fly ashes: a cement for the future. Cement and Concrete Research.29 (8), 1323-1329.
[26] Pan, Z. & Sanjayan, J. G. (2012). Factors influencing softening temperature and hot-strength of geopolymers. Cement & Concrete Composite.34, 261-264.
[27] Perraki, T., Kakali, G. & Kontoleon, F. (2003). The effect of natural zeolites on the early hydration of Portland cement. Microporous and Mesoporous Materials.61, 205-212.
[28] Sakulich, A. R. (2011). Reinforced geopolymer composites for enhanced materials greenness and durability. Sustainable Cities and Society.1, 195-210.
[29] Senthamarai, R. M., Manoharan, P. D., & Gobinath, D. (2010). Concrete made from ceramic industry waste: durability properties. Construction and Buiding Materials.25, 2413-2419.
[30] Shi, C., Jimenez, A. F. & Palomo, A (2011). New cements for the 21st century: the pursuit of an alternative to Portland cement. Cement and Concrete Research.41, 750-763.
[31] Silva de Vargas, A., Dal Molin D. C. C., Vilela, A. C. F., José da Silva, F., Pavão, B. & Veit, H. (2011). The effects of Na_2O/SiO_2 molar ratio, curing temperature and age on compressive strength, morphology and microstructure of alkali-activated fly ash-based geopolymers. Cement & Concrete Composites.33, 653-660.
[32] Songpiriyakij, S., Kubprasit, S., Jaturapitakkul C. & Chindaprasirt, P. (2010). Compressive strength and degree of reaction of biomass-and fly ash-based geopolymer. Construction and Building Materials.24, 236-240.
[33] Stefanović, G. M., Vučković, G. D., Stojiljković M. M. & Trifunović, M. B. (2011). CO_2 reduction options in cement industry-the Novi Popovac case. Thermal Science.14 (3), 671-679.
[34] Tuan, N. V., Ye, G., van Breugel, K. & Copuroglu, O. (2011). Hydration and microstructure of ultra high performance concrete incorporating rice husk ash. Cement and Concrete Research.41, 1104-1111.
[35] Wongpa, J., Kiattikomol, K., Jatuarapitakkul C., & Chindaprasirt, P. (2010). Compressive strength, modolus of elasticity, and water permeability of in organic polymer concrete. Materials and Design.31, 4748-4754.
[36] Xu, H. & van Deventer J. (2000). The geopolymerization of alumino-silicate minerals. International Journal of Mineral Processing.59 (3), 247-266.