ISSN: 2734-3340 Print; 2734-3359 Online
UI Journal of Civil Engineering and Technology Vol. 3, No. 1; June, 2021

# Compressive Strength and Water Absorption of Concrete with Palm Kernel Shell Ash as Partial Replacement for Cement

**Adeyanju D. O., Kareem M. A., Awogboro O. S., Adebanjo A. U. and Oduoye, W. O.**

Department of Civil Engineering, Osun State University, Osogbo, Nigeria.

***Corresponding Author:*** *daud.adeyanju@uniosun.edu.ng*

**ABSTRACT**

*This study evaluates Palm Kernel Shell Ash (PKSA) influence as cement replacement material on fresh and hardened concrete properties. Palm kernel shell was burnt to ashes at a temperature of 700 $^oC$ and sieved using 150 µm sieve. X-ray fluorescence analysis was conducted on PKSA in order to determine its chemical compositions. Concrete of 1:2:4 (cement, sand and granite) were produced with water-cement ratio 0.5. Portland Limestone Cement (PLC) was partially substituted with 5%, 10% and 20% of PKSA by weight for all the concrete except the control with 0% PKSA content. A total of sixty (60) concrete cubes of 150 mm × 150 mm × 150 mm size were cast and cured at 7, 14, 21, and 28 days, respectively. Slump and compacting factor tests were conducted to assess the workability of fresh concrete while the tests performed on hardened concrete were bulk density, compressive strength and water absorption. The concrete workability, density and water absorption rate decreased with increase in PKSA contents. The 28-day compressive strength of concrete decreased from 26.00 - 19.10 $N/mm^2$with increase in PKSA content from of 5-20% as against 27.8 $N/mm^2$ for the control. The targeted strength of 20 $N/mm^2$ was achieved for the concrete with the maximum of 10% PKSA. It was concluded that PKSA is suitable for replacing cement in concretes at the optimum of 10% for structures requiring the targeted strength of 20 $N/mm^2$or less.*

**Keywords:** Compacting Factor, Compressive strength, Palm kernel shell ash, Water absorption.

## 1. INTRODUCTION

The cost of traditional building materials (cement and aggregates) continues to rise as the majority of the population continues to fall below the poverty line. Reduction in the cost of building materials is essential for adequate provision of housing for the population of the teaming world. Concrete is a composite material consisting of a binder (cement), aggregates (fine and coarse) and water (Chandwani *et al*. 2014; Kareem *et al*. 2019). It is one of the oldest materials believed to be used worldwide in construction works. Cement is the binding agent and the most expensive component in concrete. Besides, several activities involved in cement production contributes approximately 5% in the global anthropogenic $CO_2$ emission which causes global warming which is harmful to lives on earth surface (Photiadis, 2015). Furthermore, the continuous production of waste from industrial and agricultural by-products creates serious environmental problems. Thus, the needs for environmental friendly building materials for low-cost buildings demands for considerations of local materials as alternative to conventional ones.

Materials obtained as by-products from industrial and agricultural processing have been found suitable as alternative materials for use to minimize cement usage. Ashes obtained after burning such materials include fly ash (Antiohos *et al*., 2005; Feng *et al*., 2018), rice husk ash (Raheem and Kareem, 2017), palm kernel shell ash (Olutoge *et al*., 2012; Appiadu-Boakye *et al*., 2019), corn cob ash (Adesanya and Raheem, 2009; Olafusi and Olutoge, 2012; Fadele and Ata, 2016), coconut shell ash (Utsev and Taku, 2012) and sorghum husk ash (Tijani *et al.*, 2018; 2019; 2020). The consideration of these materials in concrete has been described as an alternative way of utilizing such materials as supplementary cementitious materials (Antiohos *et al*., 2005). The presence of a higher amorphous silica content is responsible for their pozzolanic reactivity during the hydration phase of cement mixed with these materials. Consequently, the strength and durability of concrete are enhanced and those materials which exhibit such characteristics as a result of higher silica contents present in them are referred to as pozzolanas. Pozzolanas are classified as a silica or alumino-siliceous material that has little cementitious value in themselves, but in a finely divided form and in the presence of water chemically react with free lime from cement at room temperature to form compounds with cementitious properties (ACI 116R, 2005).

Palm kernel shell is a by-product obtained from the processing of oil palm fruit. The shell is the hard layer covering the kernel from which palm kernel oil is extracted. The broken shells are in most cases discarded after the kernels are removed, thereby constituting environmental pollution. Although, certain quantities of the shells are used as a source of fuel. Several studies have been carried out to explore the possibility of using oil palm waste in construction industries as a solution to the disposal issue of waste resulting from palm oil processing (Tay and Show, 1995). Some of the areas where Palm kernel shells are used in concrete production are, as fine or coarse aggregate replacement as well as supplementary cementitious material in the form of ash. Palm Kernel Shell Ash (PKSA) is obtained after the burning of palm kernel shell. According to Abdullah *et al*. (2006), approximately 5% of ash can be recovered out of the total quantity of palm kernel shell after the burning process.

The study by Olutoge *et al*. (2012) concluded that PKSA is suitable for use at the optimum of 10% as partial replacement for cement. Sylvester and Lukuman (2018) reported that the workability criteria of the self-compacting concrete comprising up to 25% PKSA met the standard whereas the strength of concrete decreases as the content of PKSA increases. Decreases in the workability, compressive, tensile and flexural strength of concrete were reported in the work of Olowe and Adebayo (2015) by replacing cement with up to 50% PKSA. The strength increases, however, with an increase in curing age. This study examined the workability, density, compressive strength and water absorption of concrete produced by replacing cement with 0%, 5%, 10% and 20% of ashes obtained from the locally sourced palm kernel shell within Osogbo.

## 2. METHODOLOGY

### 2.1 Material

The materials used for this study were sourced from Osogbo, Osun state, Nigeria. Dangote brand of Portland Limestone Cement (PLC) which conforms to BS 12 (1996) was purchased at a retail store in Oke-Baale area. Palm kernel shells were sourced from a mini oil palm processing mill at Egbeda area, granite and dry mining sand were collected from borrow pit while potable water was obtained from the Structural and Material Laboratory, Department of Civil Engineering, Osun State University. Table 1 shows the physical properties of cement and aggregates used in this study.

**Table 1:** Physical characteristics of constituent materials

| | Cement | PKSA | Sand | Granite |
|---|---|---|---|---|
| Specific Gravity | 3.06 | 2.60 | 2.55 | 2.71 |
| Fineness Modulus | - | - | 4.12 | 3.54 |
| Particle Size (mm) | < 0.0075 | - | < 2.36 | < 19.00 |

### 2.2 Sample Preparation

Palm kernel shell was calcined inside muffle furnace at about 700$^{O}$C for 4 hours and the ash was spread on floor to cool down for 6 hours. Thereafter, the final ash was obtained after sieving of the ash using a 150 μm sieve to obtain the ash of higher degree of fineness. Chemical analysis was carried out on PKSA sample using X-ray fluorescence analyzer according to BS EN 196-2 (1995) to examine its chemical compositions. The analysis was performed at Jawura Environmental Services Limited, Lagos State, Nigeria.

### 2.3 Concrete Mix Design and Casting

The mix proportion used for all the concrete mix in this study was 1:2:4 (cement: sand: granite). The water-cement (w/c) ratio of 0.5 was used for all the concrete mixes. In four of the concrete mixes, PLC was replaced with 5, 10 and 20% of PKSA by weight. The fourth concrete mix without PKSA served as the control. Concrete of uniform mix was obtained by hand mixing as specified in BS 1881-125 (2013). Immediately after mixing, the fresh properties were calculated (slump and compacting factor). Subsequently, the concrete was cast in concrete moulds and stored for 24 hours in a cool dry spot, during which the concrete specimens were de-moulded and cured in water until the testing ages. A total of sixty (60) concrete cubes of 150 mm × 150 mm × 150 mm size were used for bulk density, compressive strength and water absorption tests. The details of the mix proportion used for concrete production are shown in Table 2.

**Table 2**: Mix Design used for 1 m$^3$ Concrete

| | Replacement Level of PKSA (%) | | | |
|---|---|---|---|---|
| Constituent Materials | Control (0) | 5 | 10 | 20 |
| Cement (kg/ m$^3$) | 342.9 | 325.7 | 308.6 | 274.3 |
| PKSA (kg/m$^3$) | - | 17.2 | 34.3 | 68.6 |
| Sand (kg/m$^3$) | 685.8 | 685.8 | 685.8 | 685.8 |
| Granite (kg/m$^3$) | 1371.6 | 1371.6 | 1371.6 | 1371.6 |
| Total Water(kg/m$^3$) | 171.5 | 171.5 | 171.5 | 171.5 |
| Water/Cement Ratio | 0.5 | 0.5 | 0.5 | 0.5 |

### 2.4 Testing Methods

**Gradation of aggregate**

To evaluate the particle size distribution of aggregate (sand and granite) samples, sieve analysis was performed; the test was carried out as specified in BS 812-103.1 (1985).

**Slump and Compacting factor tests**

The fresh concrete workability was evaluated through the slump and compacting factor tests, performed in accordance with BS EN 12350-2 (2009) and BS 1881-103 (1993). The purpose of these tests is to assess the impact of PKSA on the ease with which it is possible to mix, place, and finish fresh concrete without losing its homogeneity.

**Bulk density**

The bulk density of hardened concrete specimens was determined at the age of 7, 14, 21 and 28 days by calculating the mass to volume ratio as given in Equation 1 according to in accordance to BS EN 12390-7 (2009).

$$Bulk\ Density\ (\rho) = \frac{mass\ of\ concrete(kg)}{volume\ of\ concrete\ (m^3)} \quad (1)$$

**Compressive strength test**

The compressive strength test was performed to determine the concrete specimen's resistance to failure under the action of compressive force at 7, 14, 21 and 28 days curing ages. The test was carried out following the procedure specified in BS EN 12390-3 (2009) using the Universal Testing Machine with a capacity of 2000 kN. The compressive strength values of concrete specimens were calculated using Equation 2.

$$Compressive\ strength\ \ (N/mm^2) = \frac{load\ at\ failure(N)}{cross\ sectional\ area\ of\ specimen(mm^2)} \quad (2)$$

**Water absorption**

Water absorption of dry concrete specimens was determined at the age of 28 days as specified in ASTM C642 (2013). After the age of 28 days, concrete specimens were removed from the curing tank and oven-dried at 100 ºC to 115 ºC until a constant weight ($x$ in kg) was obtained. Specimens were immersed in water again for 24 hours and the saturated surface dried specimen weight was obtained ($y$ in kg). The water absorption rate of concrete specimens was determined using Equation 3.

$$Water\ absorption\ (\%) = \frac{y-x}{x} \quad (3)$$

Where

y = Oven-dried specimen weight

x = saturated surface dried specimen weight.

## 3. RESULTS AND DISCUSSION

### 3.1 Gradation of Aggregates

The natural sand and granite gradation curves are shown in Figure 1. The particle size of sand conformed to zone II with the maximum particle size of 4.75 mm. The coarse aggregates ranged between 12 and 20 mm nominal size. The particle size of granite conforms to BS 882 (1992). The grain particle of granite is uniformly well-graded which indicates its potential for improving the strength of the concrete.

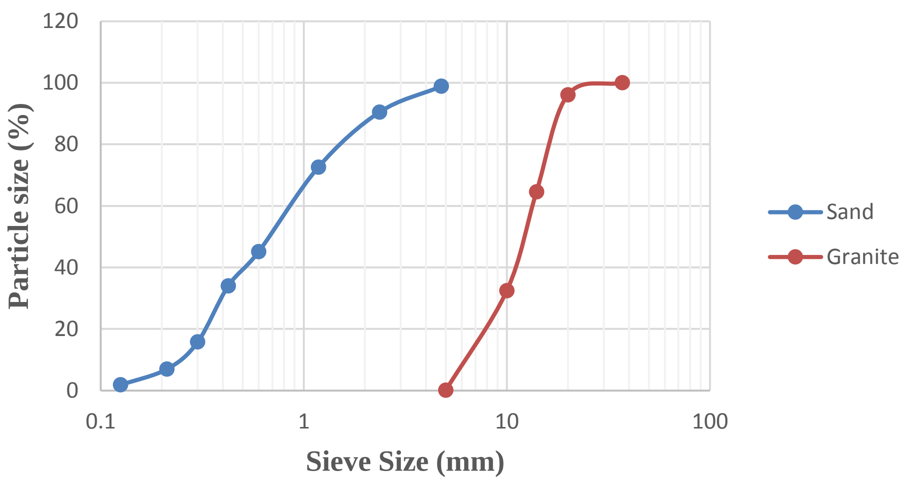


**Figure 1:** Gradation curves for sand and granite

### 3.2 Chemical Composition of PKSA

The PKSA obtained after burning palm kernel shell were grayish black in color as shown in Figure 2, the gray colour indicates the degree of its complete combustion while the black colour indicates incomplete combustion of PKSA. As shown in Table 3, the main constituents of the PKSA are silicon dioxide ($SiO_2$), aluminum trioxide ($Al_2O_3$), and ferric oxide ($Fe_2O_3$). The sum of $SiO_2$ + $Al_2O_3$ + $Fe_2O_3$ (62.16%) is above 50% and the loss on ignition (8.56%) is less than 10% for PKSA as specified by ASTM C168 (2012). Therefore, PKSA can be classified as Type C pozzolan. This agrees with Olutoge *et al*. (2012) and Appiadu-Boakye *et al*. (2019), whose studies revealed that PKSA is classified as Type C pozzolan. Thus, the PKSA used in this study exhibited pozzolanic potential. The CaO contents obtained for PKSA in this study is slightly lower than the value (8.79%) obtained by Olutoge *et al*. (2012) but higher than the value (4.27%) reported by Appiadu-Boakye *et al*. (2019). However, the value of $SiO_2$ obtained in this study is lower than the values of 54.81% and 63.05%, reported by Olutoge *et al*. (2012) and Appiadu-Boakye *et al*. (2019), respectively.

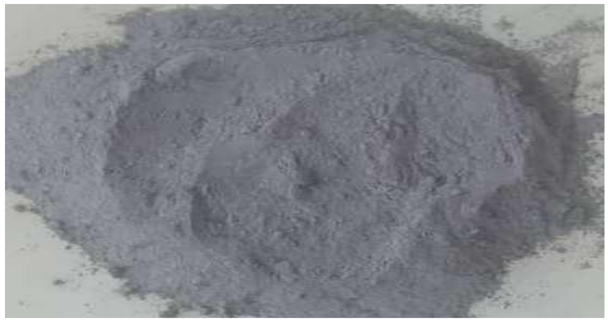

**Figure 2:** The PKSA Obtained after Calcination

**Table 3:** Chemical Properties of PKSA

| Chemical constituent | Composition (%) | |
|---|---|---|
| | PKSA | Cement |
| Silicon Dioxide ($SiO_2$) | 49.63 | 22.13 |
| Aluminium Trioxide ($Al_2O_3$) | 12.12 | 3.74 |
| Ferric Oxide ($Fe_2O_3$) | 0.41 | 2.97 |
| Calcium Oxide (CaO) | 7.96 | 63.36 |
| Sodium Oxide ($Na_2O$) | 8.24 | 0.45 |
| Pottasium Oxide ($K_2O$) | 6.21 | 0.30 |
| Manganese Oxide (MnO) | 7.64 | 0.17 |
| Loss of Ignition (LOI) | 2.25 | 8.56 |
| $SiO_2 + Al_2O_3 + Fe_2O_3$ | 62.16 | 28.84 |

### 3.3 Workability

Table 4 shows the results of the slump test of fresh concrete. The slump value of the control samples was 59 mm and decreased from 57 – 49 mm for concrete with 5-20% replacements of PLC with PKSA. This result indicates that concrete becomes less workable as the PKSA amount rises. Thus, extra water is needed to make the concrete workable (Adesanya and Raheem, 2009). The low workability of concrete containing PKSA can be attributed to the irregular shape and porous texture of PKSA particles compared with that of cement. This finding agrees with Olowe *et al*. (2019) where the presence of PKSA decreases the concrete workability. However, contrary result was reported by Appiadu-Boakye *et al*. (2019) who reported that the slump of concrete increased with increase in PKSA contents. The 0, 5 and 10% have true slump and medium workability of 59, 57, and 53 mm respectively while 20% has shear slump and low workability of 49 mm. According to Neville and Brook (2010), 0 – 25 mm is very low workability, 25 – 50 mm is low workability, 50 – 100 mm is medium workability and 100 – 175 mm is high workability. The compacting factor of concrete is presented in Table 4. From Table 4, the result of the compacting factor for control sample was 0.92 and decreased from 0.89 to 0.82 for concrete with 5-20% PKSA as replacement for OPC. The control and concrete with 5% PKSA are classified as medium workability of 0.92 and 0.89 respectively while 10% and 20% falls under low workability of 0.85 and 0.82, respectively as specified in Shetty (2005).

**Table 4:** Slump and Compacting Factor of Fresh Concrete

| PKSA contents (%) | Slump (mm) | Compacting Factor |
|---|---|---|
| 0 | 59 | 0.92 |
| 5 | 57 | 0.89 |
| 10 | 53 | 0.85 |
| 20 | 49 | 0.82 |

### 3.4 Bulk Density

Figure 3 shows the results of concrete density produced at 7, 14, 21 and 28 days. From Figure 2, the concrete density values decreased from 2500-2420 kg/m$^3$ at 7 days and 2530-2480kg/m$^3$ at 28 days as the PKSA content increases from 0 to 20%. However, the density values of concrete increased with curing age. Because of PKSA low specific gravity, which is 2.60 for PKSA compared to 3.06 for PLC, these findings suggest that PKSA concretes are lighter than PLC concretes. These results agree with the findings reported in previous studies (Olutoge *et al*., 2012; Fadele and Ata, 2016; Appiadu-Boakye *et al*., 2019) where the concrete density decreased with increase in the amount of PKSA. The increase in concrete density with curing age indicates that the rate of water absorption is significant.

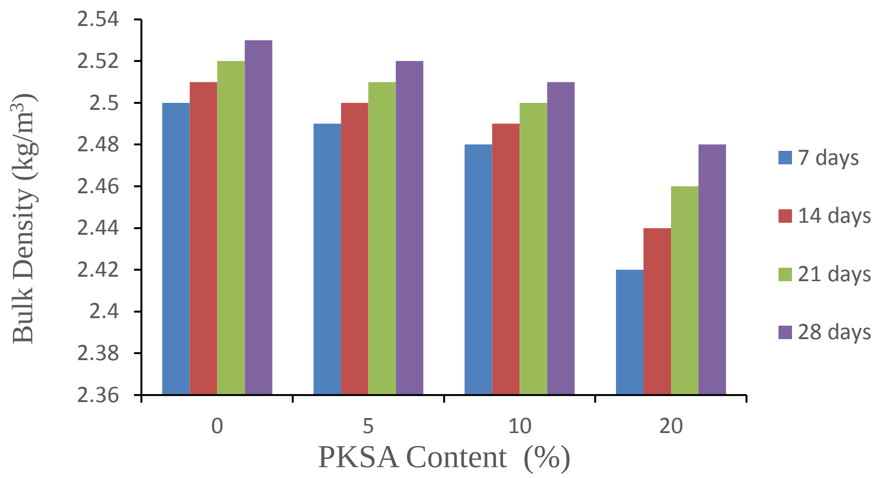


**Figure 3:** Density of the Concrete

### 3.5 Compressive Strength

Figure 4 shows the concrete compressive strength at 7, 14, 21 and 28 days. It can be seen from Figure 4 that the concrete strength rises with an increase in curing age, but decreases with an increase in the PKSA substituted cement content. The increase in strength with curing age indicates continuous hydration of concrete which agrees with previous findings (Sylvester and Lukuman, 2018; Raheem and Kareem, 2017) on the use of mineral admixture as substitution for cement in mortar and concrete. The targeted strength for the concrete mix design for this study was 20 N/mm$^2$ at 28 days. The results from this study revealed that the control concrete had the highest 28-day compressive strength value of 27.8 N/mm$^2$ which is above the design strength of 20 N/mm$^2$ while the concretes containing PKSA exhibited lower 28-day compressive strength than the control concrete. However, for the concrete with up to 10% PKSA as replacement of cement, a compressive strength of 20 N/mm$^2$ can be obtained. For concretes with more than 10% PKSA replacement level, the compressive strength goes below the targeted strength of 20 N/mm$^2$ specified characteristic of 28-day compressive strength for a M20 grade concrete in IS 456 (2000). The slow strength development which is the common features exhibited by pozzolanas is responsible for the low strength of 20% PKSA concrete of 19.1 N/mm$^2$ at 28 days (Antiohos *et al*., 2005). The decrease in strength of concrete with increase in the content of PKSA can be attributed to the lower specific gravity compared with cement indicating it's porous nature leading to high water absorption and decrease in strength of concrete. This findings is in line with Tay and show (1995) which found that the substitution of cement unground oil palm ash decreased the compressive strength of concrete. Similar trend of compressive strength was also reported by Appiadu-Boakye *et al*. (2019) who obtained a decrease in compressive strength with increase in contents of PKSA.

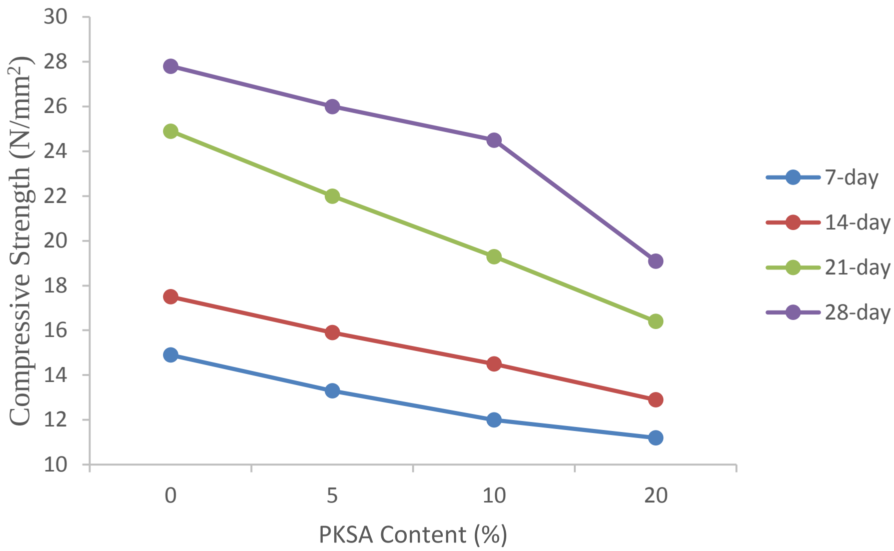


**Figure 4:** Compressive Strength of concrete with different PKSA content

### 3.6 Water Absorption

The water absorption of concrete at the 28 day curing is illustrated in Figure 5. The result of the water absorption of the control specimen is 2.50% while it decreased from 1.7-0.82% as the PKSA contents increase from 5-20%. These results indicate that the addition of PKSA decreased the water absorption of concrete produced as the percentage replacement of cement with PKSA increases. This finding is not consistent with Manap *et al*. (2016) whose study revealed that water absorption rate of concrete increased as the content of cement replaced by palm oil fuel ash increases. Contrary results was also provided by Appiadu-Boakye *et al*. (2019) where the concrete's water absorption rate increased as PKSA contents increased. The reduction in water absorption rate observed in this study could be attributed to the filler effect of PKSA which filled the voids and refined the concrete pores leading to decrease in water absorption (Al-mulali *et al*., 2015).

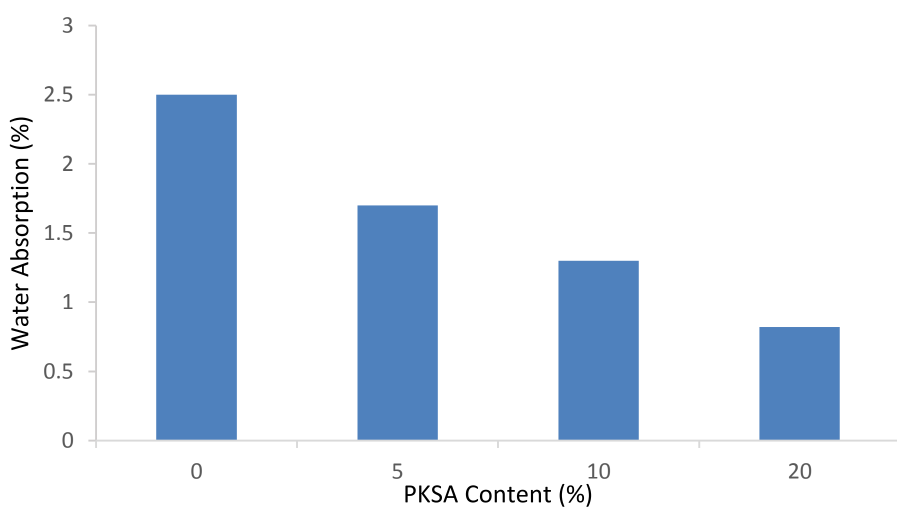


**Figure 5:** Water Absorption of Hardened Concrete

## 4. CONCLUSION

The following conclusions were drawn based on the findings from the study.

i. Due to the presence of the major chemical compounds (silicon dioxide, aluminum trioxide and ferric oxide) in PKSA as specified in the standard, PKSA is a suitable pozzolanic material.
ii. The workability of concrete decreases with the increase in the content of PKSA substituted for cement as a result of high surface area and low specific gravity of PKSA.
iii. The concrete strength increases with curing age and decreases as the percentage of PKSA in concrete increases.
iv. The water absorption rate of concrete decreases with increase in the content of PKSA in concrete as PKSA reduces the voids of the concrete.
v. Concrete containing up to 10% replacement of cement with PKSA achieved the targeted strength of 20 N/mm$^2$ while those beyond this failed to meet up with this requirement.
vi. The use of PKSA at the optimum replacement level of 10% is suitable for developing a grade M20 concrete.
vii. Treatment of PKSA with mineral or chemical additives or the combination of both is suggested for enhancement of strength and workability of concrete incorporating PKSA. Future research should consider long-term studies of strength development and durability of concrete containing PKSA.

## REFERENCES

Abdullah, K. M., Hussin, W., Zakaria, F., Muhamad, R. and Abdul Hamid, Z. (2006). POFA: A Potential Partial Cement Replacement Material in Aerated Concrete. *Proceedings of the 6th Asia-Pacific Structural Engineering and Construction Conference (APSEC 2006),* Kuala Lumpur, Malaysia.

ACI 116R (2005). Cement and Concrete Technology (Reapproved 2005), ACI Committee 116, American Concrete Institute 38800, Country Club Drive, Farmington Hills, Michigan.

Adesanya, D. A and Raheem, A. A. (2009). A Study of the workability and compressive strength characteristics of corn cob ash blended cement concrete, *Construction and Building materials*, 23: 311 - 317.

Al-mulali, M. Z., Awang, H., Abdul Khalil, H. P. S. and Aljoumaily Z. S. (2015). The incorporation of oil palm ash in concrete as a means of recycling: A review. *Cement and Concrete Composites*, 55: 129-138.

Antiohos, S., Maganari, K. and Tsimas, S. (2005). Evaluation of bends of high and low calcium fly ashes for use as supplementary cementing materials. *Cement and Concrete Composites*, 27: 349-356.

Appiadu-Boakye, K., Yeboah, K. K., Boateng, K. R. and Bukari, M. ((2019). The use of palm kernel shell ash as cement replacement in concrete. In: Laryea, S. and Essah, E. (Eds), *Proceedings West Africa Built Environment Research (WABER) Conference*, 5-7 August 2019, Accra, Ghana, 1138-1158.

BS (British Standard) (1985). Testing aggregates – Methods for determination of particle size distribution-Sieve tests. BS 812-103.1. British Standards Institution, London.

BS (British Standard) (1993). Testing Concrete - Method for determination of compacting factor. BS 1881-103. British Standards Institution, London.

BS (British Standard) (1995). Method of testing Cement – 2: Chemical analysis of cement. BS EN 196-2. British Standard Institute, 389 Chiswick high Road, London, W4 4AL.

BS (British Standard) (1996). Specification for Portland Cement. BS 12. British Standard Institution, London.

BS (British Standard) (2009). Testing fresh concrete. Slump test. BS EN 12350-2. British Standards Institution, London.

BS (British Standard) (2013). Testing Concrete. Methods for mixing and sampling fresh concrete in the laboratory. BS 1881-125. British Standards Institution, London.

BS (British Standard) (2019). Testing hardened concrete. Compressive strength of test specimens. BS EN 12390-3. British Standards Institution, London.

BS (British Standard) (2019). Testing hardened concrete. Density of hardened concrete. BS EN 12390-7. British Standards Institution. London.

Chandwani, V., Agrawal, V. and Nagar, R. (2014). Applications of artificial neural networks in modeling compressive strength of concrete: A state of the art review. *International Journal of Current Engineering and Technology*, 4(4): 2949-2956.

Fadele, O. A. and Ata, O. (2016). Compressive strength of concrete containing palm kernel shell ash. *American Journal of Engineering Research*, 5(12): 32-36.

Feng, J., Sun, J. and Yan, P. (2018). The influence of ground fly ash on cement hydration and mechanical property of mortar. *Hindawi, Advances in Civil Engineering*, 4023178, 1-7. https://doi.org/10.1155/2018/4023178

Kareem, M. A., Olawale, S. O. A., Bamigboye, G. O. and Alade, A. J. (2019). Combined influence of gravel and crushed burnt bricks on the properties of concrete. *In Proceedings of 1st International Conference on Engineering and Environmental Sciences*, Held at Osun State University. November 5-7, pp. 279-289.

Neville, A. M. and Brook, J. J. (2010). Concrete Technology, 2nd ed. Prentice Hall, Pearson Education Limited, Edinburg Gate Harlow, Essex CM20 2JE, England.

Olafusi, O. S. and Olutoge, F. A. (2012). Strength properties of corn cob ash concrete. *Journal of Emerging Trends in Engineering and Applied Sciences*, 3(2): 297-301.

Olutoge, F. A., Quadri, H. A. and Olafusi, O.S. (2012). Investigation of the Strength Properties of Palm Kernel Shell Ash Concrete, *ETASR - Engineering, Technology and Applied Science Research*, 2(6): 315-319.

Photiadis, G. M. (2015). A study of various aspects of cement chemistry and industry relevant to global warming and the low carbon and low energy molten salt synthesis of cement compounds, in Global Warming - Causes, Impacts and Remedies, B. R. Singh, Ed., InTech, London, UK.

Raheem, A. A. and Kareem, M. A. (2017). Chemical composition and physical characteristics of rice husk ash blended cement. *International Journal of Engineering in Africa*, 32: 25-35. DOI:10.4028/www.scientific.net/JERA.32.25.

Sylvester, O.O. and Lukuman, B.I. (2018). Investigation of the properties of self-compacting concrete with palm kernel shell ash as mineral additive, *Journal of Civil Engineering and Construction Technology*, 9(2): 11-18.

Tay, J. H. and Show, K. Y. (1995). Use of ash derived from oil-palm waste incineration as a cement replacement material. *Journal of Resources, Conservation and Recycling*, 13(1): 27-36.

Tijani, M. A., Ajagbe, W. O. Ganiyu, A. A., Aremu, A. S. and Ojewole, Y. N. (2020). Strength and absorption of sorghum husk ash sandcrete blocks. *Premier Journal of Engineering and Applied Sciences*, 1(1): 1 – 7.

Tijani, M. A., Ajagbe, W. O., Agbede, O. A. (2018). Modelling the effect of burning temperature and time on chemical composition of sorghum husk ash for optimum pozzolanic activity. *Journal of Engineering and Engineering Technology*, 12(2): 273 – 281.

Tijani, M. A., Ajagbe, W. O., Ganiyu, A. A., Agbede, O. A. (2019). Sustainable pervious concrete incorporating sorghum husk ash as cement replacement. *IOP Conference Series: Material Science and Engineering*, 640: 012051. doi:10.1088/1757-899X/640/1/012051