Journal of Engineering Research, Volume 26, Number 1, Octoberber 2021

Flow and Strength Properties of Binary Blended Self-Compacting Concrete Containing Bio-Ash

K. A. Olonade[1*], W. Schmidt[2] and M. O. Adeoye[3]
[1*]*Department of Civil & Environmental Engineering, University of Lagos, Akoka, Nigeria*
[2]*Bundesanstalt für Materialforschung und- prüfung, Berlin, Germany*
[3]*Department of Civil Engineering, Obafemi Awolowo University, Ile-Ife, Nigeria.*
Correspondence Author Email: kolonade@unilag.edu.ng

Abstract
Palm kernel shell ash (PKSA) is a known pozzolanic material used in normal concrete with positive results, but there is dearth of knowledge on its effect on self-compacting concrete. Thus, flow properties of self-compacting concrete (SCC) containing PKSA as partial replacement for cement was studied and presented in this paper. Palm kernel shells were burnt at temperature of 700 ℃ for an hour to obtain ash. The ash was used to replace ordinary Portland cement (OPC) at 0%, 5%, 10%, 15% and 20% replacement levels in a predesigned SCC mix. Flow properties of the blended SCC and normal SCC were measured. The flow parameters determined were Slump flow, L-Box, V-Funnel, Sieve Stability and Visual Stability Index using standard procedures. Compressive strength and density of the hardened concrete were determined. The results showed that increase in proportion of PKSA decreased the flow properties of SCC but were within the limit at up to 15% replacement, while the strength activity index was more than 75% at up to 10% PKSA content. The study concluded that it is possible to produce SCC with up to 10% PKSA content. This study further affords the authors the leverage to extend experience to the use of cassava peel ash in SCC.

Keywords: Blocking ratio, pozzolan, segregation resistance, strength and workability.

1.0 INTRODUCTION

Though the SCC was initially conceived to mitigate challenges due to shortage of experienced labour in construction industries in the early 1980s but it has gained prominence and has become a preferred concrete. This is more so, when it is required to fill formwork for large structures that contain heavy and highly congested reinforcing bars, where compaction becomes extremely difficult. Other added advantages of SCC over normal concrete include reduction in cost of construction due to compaction and reduction in health hazard attributed to noise from compaction operation as well as faster construction, reduced manpower, better finishes, ease of placement (EFNARC, 2002 and Musa and Nura, 2017).

Unlike normal concrete that required medium slump value for workability, SCC requires high slump. To achieve high slump without segregation and bleeding is a major challenge in the production of SCC. Apart from the fact that superplasticizers are incorporated to aid flowability of the concrete, other approaches have been proposed for the design of SCC. According to Pai et al. (2014), sand content should be increased by 4% or 5%, while limiting the quantity of coarse aggregate. Okamura and Ouchi (2003) posited that the method of achieving SCC involves not only high relative slump of paste or mortar, but also resistance to segregation, when the concrete flows through narrowed zone of reinforcing bars. The shape and particle size of aggregates also play an important role in producing high performance SCC (Aijaz and Khadirnaikar, 2014). The Japanese method has been adopted by many countries in Europe. In the method, both coarse and fine aggregates have been limited to 50% of the parked density of the concrete and mortar respectively (Brouwers and Radix, 2005). What is apparent from the literature to be the most satisfactory condition to produce SCC, as reported by Domone (2007), is the high powder volume content at relatively low water/powder with significant quantity of superplasticizer. Combination of these seem to achieve low yield stress and moderate plastic viscosity, which eventually leads to high fluidity and stability.

Nevertheless, requirement for higher powder content suggests that more cement will be required in producing SCC compared to normal concrete. This might be a serious drawback to the choice of SCC, because of sustainability and the need to get rid of environmental hazards attributed to cement production. It is a known fact that cement industry emits substantial amount of greenhouse gases to the atmosphere, as for every ton of Portland produced, about one ton of CO_2 is emitted (Robbie, 2018). In 2016 alone, the world cement production generated around 2.2 billion tonnes of CO_2-equivalent representing about 8% of the total global CO_2 emission (Rodgers, 2018). Thus, reducing cement content of SCC by partial replacement with supplementary cementitious materials (SCMs) and or pozzolanic materials remains the only path to sustainable SCC, while challenges associated with high heat of hydration induced crack would be mitigated. There are substantial works that have been reported in this regard.

Musa and Nura (2017) investigated self-consolidating high performance concrete (SCHPC) by incorporating palm oil fuel ash (POFA) and pulverized burnt clay (PBC) as SCMs. Both POFA and PBC were used to replace 5%, 10% and 15% of cement by weight. Workability and strength properties of the mixes were determined. Their results showed that SCHPC mixes exhibit excellent workability but for compressive and splitting tensile strength, it was found that only mix, which contained 5% POFA and 5% PBC was comparable to the control mix. Zoran et al. (2008) also incorporated silica fume and fly ash as replacement for cement in producing SCC with positive results. Other materials that have been explored and found as potential ingredients for SCC are rice husk ash, ground granulated blast-furnace slag as well as corn cob ash (Safiuddin *et al*., 2007; Pai *et al* 2014 and Olafusi *et al*., 2015).

Despite abundant availability of bio-wastes such as palm kernel shells, cassava peels, sugarcane straws that have long history of being processed for use as pozzolans in producing normal concrete with excellent results (Abdullahi *et al*., 2006, Salau and Olonade, 2011 and Frias *et al*., 2007), there is still dearth of study on their use for SCC. The authors have already initiated studies in this regard. For this present work, suitability of PKSA as partial replacement for cement in producing SCC is presented

2.0 MATERIALS AND METHODS

2.1 Materials

The palm kernel shell ash was obtained from dumpsite of blacksmith in Osogbo, Nigeria and was sieved using 150 µm sieve size; the amount passing through the sieve was used for this study. While River sand and granite of maximum nominal sizes of 3.35 mm and 12.5 mm were used as fine and coarse aggregates, respectively, ordinary Portland cement (OPC) of grade 32.5 N was used as binder. Superplasticizer used was Rheobuild 850.

2.2 Mix design

The mix design adopted for this study was modified Japanese concept for design of SCC which was based on a method proposed by Okamura and Ozawa (1995). The mix design used was:

(i) Coarse aggregate content was first taken as 50% of the solid volume
(ii) Fine aggregate content was also taken as 40% of the mortar volume
(iii) Water-powder ratio was varied from 0.35 to 0.5
(iv) Super plasticizer dosage of 115 ml was used.

After various mix trials, mix proportion of 1:2:1.5 with water/cement ratio of 0.5 was found to meet the requirement of SCC. This mix was therefore adopted for the remaining mixes with PKSA replacing cement at 5, 10, 15 and 20% volume weight. The mix was done manually. Aggregates, cement and powder were first mixed in dried form until a uniform distribution was attained. Then water was added to and mixed thoroughly. After which superplasticizer was added. Table 1 represents the composition of SCC mixtures per cubic meter. Concrete cubes of sizes 100 mm were cast and demoulded after 24 hours. The cubes were then cured in fresh water for 7, 14, 21 and 28 days. A total of 60 concrete cubes were cast.

Table 1: Mix proportion of SCC

Materials	Percentage proportion of PKSA as replacement for OPC (%)				
	0	5	10	15	20
Water/cement ratio	0.50	0.50	0.50	0.50	0.50
Water content (kg/m^3)	237.20	237.20	237.20	237.20	237.20
Cement (kg/m^3)	474.50	450.78	427.05	403.33	379.60
PKSA (kg/m^3)	0.00	19.65	39.31	58.97	78.62
Sand (kg/m^3)	949.00	949.00	949.00	949.00	949.00
Granite (kg/m^3)	711.70	711.70	711.70	711.70	711.70
SP (ml/m^3)	2875.00	2875.00	2875.00	2875.00	2875.00
Aggregate/binder	3.50	3.53	3.56	3.59	3.62

2.3 Methods

2.3.1 Determination of particle size distribution

Sieve analysis test was conducted on the aggregates to determine their particle size distribution. This test was conducted in accordance with the provision of BS 882 (1992). Thereafter, grading parameters such as fineness modulus, coefficient of uniformity, as well as coefficient of curvature were determined from the grading curves obtained.

2.3.2 Determination flowability property

Cone similar to slump cone for normal concrete was used to measure flow property of the concrete mixes. The procedure specified in EFNARC (2002) was adopted for this test. Time required for the concrete to cover 500 mm diameter spread circle (T_{50cm} time) from the time the slump cone was lifted was noted. Average flow diameters of the spread after the concrete stopped flowing was measured to ascertain the slump flow value. The results obtained were used to compute slump flow (S_f) and relative spread area (Γ_c) of the concrete mixes, using Equations 1 and 2, respectively. The same approach was used by Okamura and Ouchi (2003).

$$S_f = \frac{D_1 + D_2}{2} \qquad (1)$$

$$\Gamma_c = (D_1 D_2 - D_0{}^2)/D_0{}^2 \qquad (2)$$

Where D_1 and D_2 are flow diameters measured perpendicular t each other, while D_0 is the bottom diameter of the slump cone (200 mm in this case).

2.3.3 Determination of filling ability of the concrete mixes

The filling ability of each concrete mix was determined using V-Funnel test. The procedure described in the Specification and Guidelines for Self- Compacting Concrete of EFNARC (2002) was followed. The time required for emptying the concrete filled in V-funnel completely in seconds was measured and average of three measurements was determined.

Thereafter, v_c (relative funnel speed) was determined from Equation 3 as a measure of viscosity as proposed by Okamura and Ouchi (2003).

$$v_c = 10/t \qquad (3)$$

Where t(sec) was the time for concrete to flow through the funnel.

To measure segregation resistance, the V-funnel was refilled with concrete, which was allowed to sit for 5 minutes. The door of the V-Funnel was again opened and the flow time was recorded.

2.3.4 Determination of passing ability property

L-Box test was used to measure passing ability property of the concrete mixes, following the guidelines of EFNARC (2002). When the concrete stopped flowing, the height of concrete at the obstruction (h1) was measured, while h2, corresponding to the height of concrete at the end of the horizontal leg was equally measured. Thereafter, the blocking ratio (h2/h1) was computed for each of the three tests conducted on each concrete mix and average value was determined.

2.3.5 Determination of segregation resistance

Wet Sieving Stability Test was carried for measuring segregation resistance of the concrete mixes. 10 liters of the concrete sample was placed in a bucket and allowed to sit for 15 minutes, to permit any internal segregation to occur, while keeping the container sealed to prevent evaporation. At the expiration of 15 minutes, the top 2 liters of the concrete sample was poured through a height of 500 mm into a sieve of size 5 mm. The mortar passing through the sieve was received in a sieve pan after 2 minutes of pouring. The mass of the concrete poured onto the sieve (Ma) and that of mortar in the sieve pan (Mb) were measured and used to calculate the segregation resistance (SR) using Equation 4. This procedure was recommended by Koehler and David (2003).

$$SR = \frac{M_a}{M_b} \times 100\% \qquad (4)$$

2.3.6 Determination hardened properties

Compressive strength of the concrete cubes were determined, using compressive machine he procedure prescribed in BS1881 (1993). Average of three cubes was determined. Before crushing, weight of each cubes was measured in air (W_a) and under water (W_w) to determine its density. The density of the cubes were then estimated from Equation 5. Similar method was used by Brouwers, and Radix (2005).

$$\rho_{\text{cube}} = \rho_{\text{w}} \frac{W_a}{W_a - W_w} \qquad (5)$$

3.0 RESULTS AND DISCUSSION

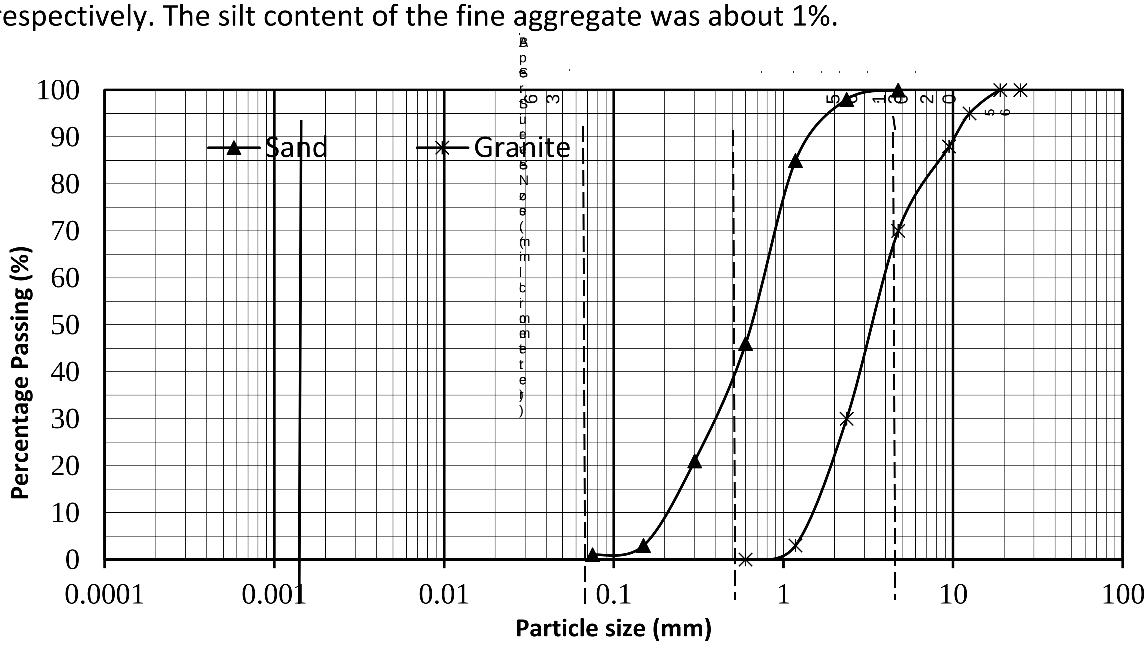
3.1 Materials characterization

Table 2 shows the oxide composition as well as physical properties of the ordinary Portland cement (OPC) and PKSA used in the study. The total amount of SiO_2, Al_2O_3 and Fe_2O_3 present in PKSA was 86.61% which was more than the minimum required (50% Min.), for Type C Fly Ash; while its Sulphur oxide (SO_3) content was about 0.08% which was less than the maximum required (5.00% max), and Loss on Ignition (LOI) was about 4.53% which was less than the maximum required (6.0% max) as specified by ASTM C618 (2006). On the other hand, the cement could be classified as CEM II. The fine content of the cement was more than that of PKSA as shown by the quantity of materials retained on the 90 μm sieve size, while PKSA was less dense that cement.

Table 2: Chemical and physical properties of OPC and PKSA

Material	Oxides (%)										LOI	SG	Retained on 90 μm (g)
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	TiO_2	P_2O_5			
OPC	17.89	3.85	2.38	55.45	1.54	1.76	0.10	0.24	0.20	0.31	10.80	3.09	83.70
PKSA	55.89	6.67	24.05	1.65	0.98	0.08	0.30	2.32	1.03	0.69	4.53	2.56	140.00

The grading properties of the aggregates are shown in Figure 1. It is shown that about 95% of the fine aggregates passed through 1.18 mm and 12.5 mm sieve for the fine and coarse aggregates respectively. The silt content of the fine aggregate was about 1%.



	fine	medium	coarse	fine	medium	coarse	fine	medium	coarse	COBBLES
	SILT			SAND			GRANITE			

Figure 1: Grading curves of aggregates mix

Table 3: Flow of Fresh SCC Mixes at Different Content of PKSA

Properties	PKSA Content (%)					Limit[*]
	0	5	10	15	20	
T_{50cm} slump flow (s)	3.00	3.41	3.44	3.50	6.70	2 – 5
Slump Flow, S_f (mm)	665	645	615	560	550	650 - 800
V-Funnel (s)	10.50	11.10	11.50	11.90	12.60	8 - 12

[*](EFNARC 2002)

The filling ability of blended cement-PKSA concrete was equally investigated, using V-Funnel test. The results indicated that the V-Funnel flow time ranged from 10.50 s to 12.60 s, with normal concrete having lowest flow time of 10.50 s. Flow time then increased with increase in PKSA content. Apart from 20% PKSA concrete that had flow time higher than recommended upper limit, other mixes had flow times within the permissible range for a concrete to be classified as self-compacting (Table 3). These results further confirmed that presence of PKSA caused increased in plastic viscosity of concrete mix, depending on the quantity.

3.2 Effect of PKSA on relative flow velocity and flow area of concrete mix

The slump and V-Funnel tests were also used to assess deformability and viscosity of the concrete mixes. The results are presented in Figure 2 along with the boundary recommended for SCC. Values between 8 and 11.3 were prescribed for lower and upper boundary for deformability respectively, while between 0.5 and 1.0 s^{-1} were recommended for viscosity Nepomuceno and Pereira-de-Oliveira (2008). The result shows that only the concrete mixes containing 5% and 10% content of PKSA as well as the normal concrete (0%) fell within the boundary, indicating that they met the rheological properties considered for SCC. But concrete mixes with 15 and 20% PKSA content fell outside the box. The same approach was adopted by Pereira-de-Oliveira (2014) to classify SCC containing recycled aggregate.

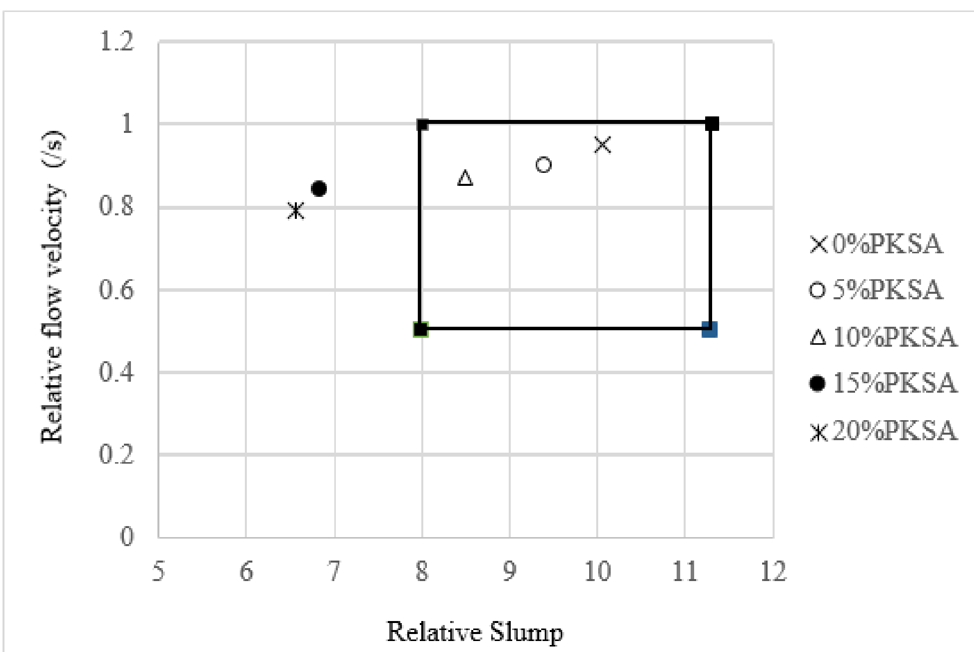


Figure 2: Rheological parameters of concrete containing PKSA

These results suggested that inclusion of PKSA had effect on both the relative flow velocity and relative spread area but the effect was more pronounced with content of PKSA above 10%, suggesting that it may not be appropriate to use more than 10% PKSA proportion as replacement for cement in this mix design to meet rheological properties for SCC, unless higher amount of SP is used or w/b ratio is increased to facilitate flow. Meanwhile, care must be taken in this regard as high amount of SP in concrete or higher water in concrete could lead to segregation and set retardation as well as other undesirable properties in the hardened concrete (Jayasree et al., 2011).

3.3 Passing properties and segregation resistance

Figure 3 shows effect of PKSA on both the segregation resistance and passing properties of SCC. There was marginal reduction ($<$ 10%) in segregation resistance (SR) and blocking ratio (BR), when 5% of cement was replaced by PKSA. But the reduction became more pronounced as PKSA content increased up to 20% PKSA. Nevertheless, the SR for concrete containing up to 15% PKSA fell within the range of 5 and 15% recommended for acceptable SR for SCC, indicating that the concrete mixes would not segregate and are therefore fit for normal used, while SR for 20% PKSA concrete was about 4.2% ($<$5%), suggesting that the mix was too stiff and would be difficult for good finish. As mentioned earlier, presence of PKSA reduced the amount of free water required for flow, consequently reduced spread of concrete over the sieve. Since, the method used (sieving method) measures the weight of mortar that passed through the sieve against the quantity retained in the sieve; lesser mortar passed through the sieve as the PKSA content reduced, therefore, SR reduced with increase in PKSA content. This is further reflected in the increased in aggregate-binder ratio of the mix as the PKSA content increased (Table 1).

In the case of BR, the value depends on the height of concrete at the end of the horizontal leg of the L-Box compared to the height at the obstruction, which equally depend on the lateral flow of the concrete. PKSA is known to be responsible for increased plastic viscosity and reduced spread flow due to increased friction (Table 2 and Figure 3). Presence of PKSA in the concrete mix was responsible for retarded horizontal flow and thus, the concrete reach lesser height at the end of the horizontal leg of the L-Box. The implication of this effect is that concrete containing higher PKSA ($> 15\%$) reduced the paste content of the concrete mix, and therefore the passing ability.

3.4 Compressive strength of the SCC containing PKSA

Figure 4 shows that PKSA has greater influence on the compressive strength of SCC. The trend is that the strength reduced with increase in PKSA content, especially at early ages of 7 and 14 days but there was marked decrease with SCC containing more than 10% PKSA. The strength curves of 5 and 10% PKSA concrete tends to merge up with the normal concrete at 28 days. While the strength of normal concrete (0%) appears to flatten between 21 and 28 days, those of 5 and 10% PKSA seem to be rising. Quantitatively, the strength of normal concrete increased from 21.77 N/mm^2 at 21 days to 22.32 N/mm^2 at 28 days, representing an increase of about 2.5%, while 5% and 10% PKSA concretes increased, during the same periods, by about 8.5% and 5.1%, respectively.

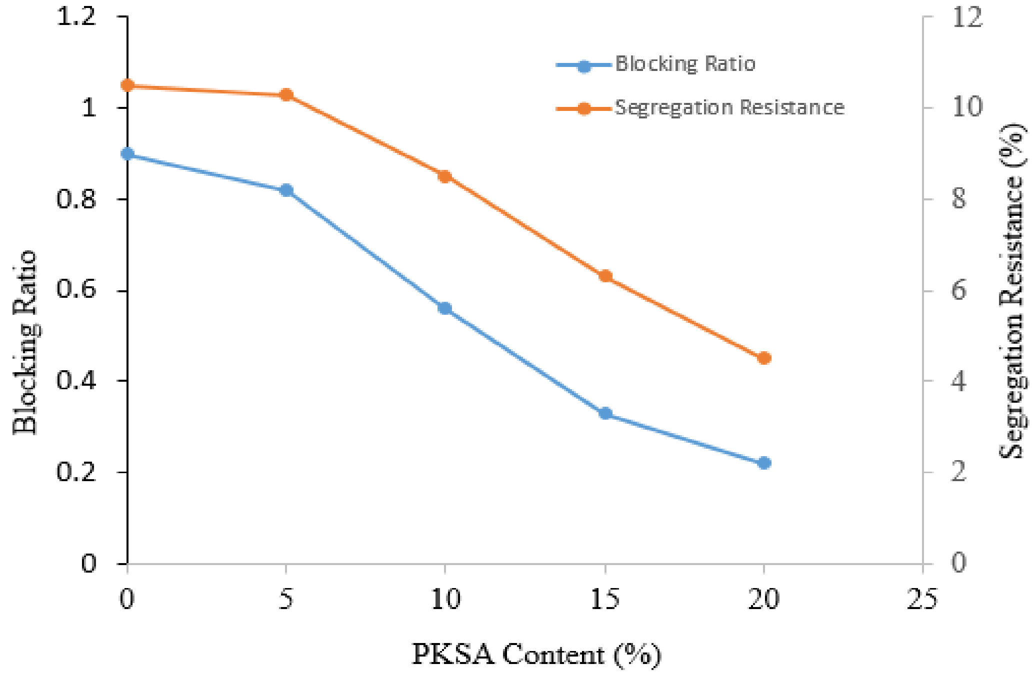


Figure 3: Effect of PKSA content on Blocking Ratio and Segregation Resistance

There is a strong possibility that PKSA contribute to later strength at these dosages (5% and 10% PKSA). In fact, the strength activity index (SAI) of the mixes were 94% and 84% respectively, far above 75% recommended by ASTM C618 (2006) (Table 3). According to ASTM C618 (2006), SAI is defined as the ratio of strength of concrete containing SCM to the strength of normal concrete at a given age (especially, at 28 days). It is used as a measure to accept or reject a material as pozzolan. Regarding SCC containing more than 10% PKSA, the strength was found to be consistently decreasing and there seem not to rise, even beyond 28 days (Figure 4). Further, the SAIs were did not also meet the recommended value.

A possible explanation for this behaviour is that presence of PKSA contained SiO_2, which has potential to react pozzolanically with by-product of cement hydration (CaOH), producing additional cementitious material contributing to strength development. Due to low reactivity of PKSA, it could not contribute to early strength but later strength. However, when the PKSA content increased (above 10%), as earlier shown in this study, the mix tend to stiff and less compacted. Consequently, void could be created within the concrete matrix, leading to reduction in strength. This is further indicated by their relative low densities (Table 4). Findings from this study, therefore, suggest that it is possible to produce SCC with 10% of cement replaced with PKSA without impairing its performance.

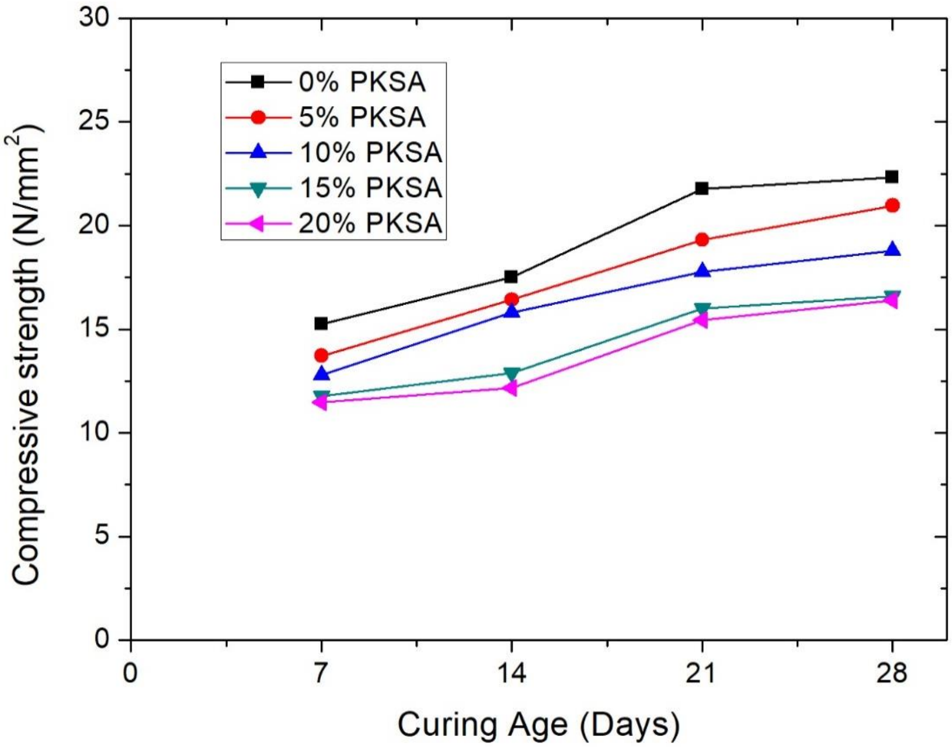


Figure 4: Compressive strength of PKSA

Table 4: Density and Strength Activity Index (SAI) at different content of PKSA

PKSA Content (%)	Density (kg/m^3) Curing Age (Days)				SAI (%) Curing Age (Days)			
	7	**14**	**21**	**28**	**7**	**14**	**21**	**28**
0	2416	2434	2457	2483	100	100	100	100
5	2406	2425	2433	2441	89	94	89	94
10	2397	2382	2394	2417	84	90	82	84
15	2270	2346	2371	2381	77	74	73	71
20	2225	2237	2231	2239	75	69	71	73

4.0 CONCLUSION

Rheological and hardened properties of SCC containing different proportions of PKSA as replacement for cement were studied. Based on the findings from the study, the following conclusions were drawn;

i. PKSA contains all the main chemical constituents to meet the requirements for use as pozzolanic material.

ii. PKSA has the potential to increase plastic viscosity, increase yield stress and thus retard flow of concrete.

iii. Palm kernel shell ash can be used to produce SCC with acceptable filling ability, passing ability and adequate segregation resistance, when up to 15% of cement content is replaced by it.

iv. Presence of PKSA improved later age strength of the concrete at not more than 10% content.

ACKNOWLEDGEMENT

The Authors acknowledge financial support of the Federal Ministry of Education and Research (BMBF), Berlin for the funding of Local-Care Project under the German-African Innovation Incentive Award.

REFERENCES

Abdullah K.M., Hussein W., Zakaria F., Muhamad R., 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), 35 – 42.

Aijaz A.Z.and Khadirnaikar R. B. (2014). An overview of the properties of self-compacting concrete", *IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE*), 35-43

ASTM C618. (2006). Standard Specification for Coal Fly Ash and Raw or calcined Natural pozzolan for use in concrete. ASTM Inc. US.

Brouwers, H.J.H. and Radix H.J. (2005). Self-Compacting Concrete: Theoretical and experimental study*, Cement and Concrete Research*, 35:2116–2136.

BS 882 (1992). Specification for aggregates from natural sources for concrete, British standards Institution, UK.

BS1881- 107 (1993). Method for determination of density of compacted fresh concrete, British standards Institution, UK.

Domone P.L. (2007). A review of the hardened mechanical properties of self-compacting concrete, *Cement and Concrete Composite,* 29: 1-12.

EFNARC (2002). Specification and guidelines for self-compacting concrete, EFNARC, Association House, 99 West Street, Farnham, Surrey GU9 7EN, UK.

Frías, M., E. Villar Cociña and E. Valencia-Morales (2007). Characterisation of sugarcane straw waste as pozzolanic material for construction: Calcining temperature and kinetic parameters, *Journal of Waste Management,* 27:533-538.

Igarashi S., Watanab A., Kawamura M., (2005). Evaluation of capillary pore size characteristics in high-strength concrete at early ages, *Cement and Concrete Research*, 35(3):513-519.

Jayasree, C., Manu S and Ravindra G. (2011). Cement-superplasticizer compatibility - Issues and challenges, *Indian Concrete Journal,* 85(7):48-60.

Koehler, E. P. and David W. F. (2003). Summary of concrete workability test methods, *International Center for Aggregates Research*, The University of Texas at Austin, Cockrell Hall 5.200, 1 – 93.

Koehler, E. P. and D. W. Fowler (2007). Inspection manual for self-consolidating concrete in precast members, Project 0-5134: Self-Consolidating Concrete for Precast Structural Applications, Center for Transportation Research, the University of Texas at Austin. 1- 35.

Musa, A. and Nura B. (2017). Performance of self-consolidating high performance ternary blended concrete, *Noble International Journal of Scientific Research*, 1(2): 44-49.

Nepomuceno, M. and Pereira-de-Oliveira L. A. (2008). Parameters for self-compacting concrete mortar phase, *American Concrete Institute Special Publication.* 323–40.

Okamura, H. and Ouchi, M (2003). Self-compacting concrete. *Journal of Advanced Concrete Technology*, 1(1): 5 – 15.

Okamura, H. and Ozawa, K. (1995). Mix-design for self-compacting concrete, *Concrete Library of JSCE*, 25:107 – 120.

Olafusi, O.S., Adewuyi, A. P., Otunla, A. I. and Babalola, A. O. (2015). Evaluation of fresh and hardened properties of self-compacting concrete, *Open Journal of Civil Engineering*, 5: 1-7.

Pai B. H. V, Nandy M., Krishnamoorthy A., Sarkar P. K., Pramukh and Ganapathy, C. (2014). Experimental study on self-compacting concrete containing industrial by products, *European Scientific Journal*, 10(12): 292-300

Pereira-de-Oliveira, L. A., Nepomuceno, M. C. S., Castro-Gomes, J. P. and Vila, M. F. C. (2014). Permeability properties of self-compacting concrete with coarse recycled aggregates, *Construction and Building Materials,* 51:113–120

Robbie, M. A. (2018). Global CO2 emissions from cement production, *Earth Syst. Sci. Data*, 10, 195–217.

Rodgers, L. (2018). Climate Change: The massive CO_2 emitter you may not know about. BBC News. Available: https://www.bbc.com/news/science-environment-46455844. Accessed: 7th January, 2019.

Safiuddin M., West J. S. and Soudki K. A., (2010). Hardened properties of self-consolidating high performance concrete including rice husk ash, *Cement and Concrete Composites*, 32: 708-717

Safiuddin, M. H. M. Isa, and Jumaat. Z. (2011). Fresh properties of self-consolidating concrete incorporating palm oil fuel ash as a supplementary cementing material, *Chiang Mai J. Sci*. 38(3):389-404.

Salau, M. A. and Olonade K. A. (2011). Pozzolanic potentials of cassava peel ash, *Journal of Engineering Research*, 16(1):10-21.

Tanqchirapat W., Saeting T., Jaturapitakkul C., Kiattikomol K. and Siripanichgorn A., (2007). Use of waste ash from palm oil industry in concrete, *Waste Management*, 27(1): 81-88,

Zoran Grdić, I. D. and GordanaT. Ć. (2008). Properties of self-compacting concrete with different types of additives, *Architecture and Civil Engineering*, 6(2): 173-177.