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Effects of Cassava Peel Ash Admixed with Rice Husk Ash as Alternative Binders in Self-Compacting Concrete

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Abstract

Many developing countries, including Nigeria, are concerned about the increasing environmental contamination caused by agricultural wastes such as rice husk, maize cob, cassava peels, and groundnut shells. Recycling such wastes into new building materials could be a realistic solution to a variety of pollution problems. This study aimed at determining experimentally, the characteristics of self-compacting concrete made from Cassava Peel Ash (CPA) mixed with Rice Husk Ash (RHA). Slump flow, passing ability, and segregation resistance tests were performed to assess the workability of Self-Compacting Concrete (SCC) produced from CPA and CPA blended with RHA. Compressive strength, splitting tensile and flexural strength tests were carried out on 540 specimens with varying degrees of CPA and CPA-RHA substitution. The results obtained showed that the compressive, splitting, and flexural strengths of SCC formed from CPA decreased with increasing CPA content whereas increasing CPA-RHA content increased the strengths up to 10% cement replacement with blended CPA-RHA. It was also found that 5% CPA and 15% CPA-RHA contents are the best cement replacements by weight for self-compacting concrete with grade 35.

Keywords: *Portland cement, Self-compacting concrete, Rice husk ash, Cassava peel ash, Strength, Super-plasticier*

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Introduction

Concrete is a synthetic building material produced by accurately combining cement, fine aggregate, coarse aggregate, and water. It is one of the most extensively used building materials in the world due to its flexible application, ability to meet performance criteria in terms of strength, and capacity to be moulded into a range of forms and sizes (Kayode and Ilessama, 2015). Self-Compacting Concrete (SCC) is one of the most notable developments in concrete technology during the previous decade. SCC is a highly workable, stable concrete that flows easily over congested reinforcement, filling formwork without consolidation or considerable segregation. The hardened SCC is dense, uniform, and conventionally made using the same Portland Cement (PC) as traditional vibrated concrete. SCC improves surface finish attributes and removes the need for compaction, saving time, lowering labor costs, and conserving energy (Kanniyappan et al., 2016).

Global warming is one of the most serious environmental challenges today, and it is produced by the release of greenhouse gases such as carbon dioxide (CO_2) and methane (CH_4) into the atmosphere during the manufacture of Portland cement. According to Hardjito et al. (2004a), the global cement sector contributes around 1.65 billion tons of greenhouse gas emissions per year. As a result, there is a need to introduce alternative ecological cementitious binders based on industrial or agricultural waste or by-products such as blast furnace slag, fly ash, rice husk ash, and cassava peel ash, which have a very small Greenhouse footprint when compared to conventional ordinary Portland cement production (Duxson et al., 2007).

Cassava is a root and tuber crop grown in all ecological zones of Nigeria, although primarily in the country's southern and middle belts. According to Adesanya et al. (2008), cassava peel accounts for 20-35 percent of the weight of the tuber, especially when hand peeling. Cassava Peel Ash (CPA) is a byproduct of the burning of peels generated during cassava processing and has been proven to be pozzolanic when calcined at 700 degrees Celsius for 90 minutes, according to Salau and Olonade (2011). The abundance of cassava peel wastes in the vicinity of garri processing centers, as seen in Fig. 1, is cause for worry. These pollutants cause pollution because attempts to eradicate them through incineration or natural decomposition are sometimes ineffective. As a result, recycling such trash into new building materials could be a realistic solution to the problem of environmental pollution.

Fig. 1: Dumpsites of cassava peels (Okike et al., 2016)

Meanwhile, preliminary studies such as Olonade et al. (2014) and Owolabi et al. (2015), have shown that CPA does not meet the minimum requirement of ASTM – C618 (2008), which is 70% of the sum of silicon, aluminum, and iron oxides for it to be used as a pozzolan, necessitating the introduction of RHA as a blending material, which is an established pozzolanic material (Foong et al., 2015; Mahmud et al., 2016; Said et al., 2017). Rice husk, on the other hand, was widely dumped into streams, creating pollution and poisoning of springs until it was proven to be a helpful mineral component for concrete (Sua-iam, and Makul, 2012; Krishna et al., 2016). It is a super-pozzolana with a high concentration of silicon dioxide (SiO_2) and is approved for use in concrete manufacturing (Sheth et al., 2014; Aboshio et al., 2018). The optimal temperature for RHA production is between 600^{o}C and 700^{o}C. In this paper, an experimental investigation is carried out into the workability and strength properties of self-compacting concrete produced from CPA and CPA blended with RHA.

2. Materials and methods

2.1 Materials

Portland cement (primary binder), cassava peel ash, and rice husk ash as pozzolanic binders with specific gravities of 2.01 and 2.07, respectively, were utilized in this investigation. Cassava peels were collected from different cassava farmers' disposal sites in Dadin-Duniya Village, Gabasawa Local Government Area, Kano, Nigeria. They were collected in 50 kg sacks, washed, and dried in the air for 48 hours to remove moisture. Rice husks came from rice milling mills in Kura Town, Kura Local Government Area, Kano State, Nigeria. They were each burned for two (2) hours at a controlled temperature of 60°C, and then sieved through a 75 µm B.S. sieve to produce fine cassava peel ash and rice husk ash. Table 1 shows the chemical composition of cement, CPA, and RHA as determined by an X-Ray Fluorescence (XRF) test.

Table 1: Binders oxides' analysis

Oxide	Cement	CPA	RHA
SiO_2	15.614	43.164	82.171
Al_2O_3	3.222	3.945	0.403
Fe_2O_3	3.343	3.320	1.680
CaO	74.088	21.090	5.518
MgO	0	3.395	1.331
CuO	0.003	0.003	0.002
MnO	0.045	0.056	0.345
Cr_2O_3	0	0.005	0
TiO_2	0.058	0.475	0.164
ZnO	0.004	0.055	0.222
LOI	3.13	15.27	4.940
SG	3.16	2.01	2.07
Fineness	13	26	28

The clean river sand (fine aggregate) with a specific gravity of 2.62 was obtained from the River Challawa in Kano, Nigeria. The fine aggregate was sieved and classified as Zone 2 using the BS EN 882 (1992) grading limit, as shown in Fig. 1. As coarse aggregates, 20 mm machine crushed gravel stone was employed. Potable water from the laboratory of the department of Civil Engineering, Bayero University Kano was used for mixing and curing. The specific gravity and crushing value of the aggregate are 2.7 and 22%, respectively. Drinking water that complied with ASTM C1602-12 (2012) was utilized for batching and curing at the SCC. To improve the workability of the SCC, a chloride-free liquid super-plasticizer was added at 1.4 percent weight of binder.

2.2 Sample preparation and testing

To produce a mix design with grade 35 SCC strength, EFNARC (2005) requirements and guidelines were employed in conjunction with experimental trials. The superplasticizer was dosed at 1.4 percent of the weight of the binder, as advised by the manufacturer. The proportions for various CPA and RHA substitutions are reported in Tables 2 – 3. The consistency and setting time tests for CPA and RHA pastes were performed in accordance with BS EN 196-3 (2005) using Vicat apparatus at each replacement level of 0, 5, 10, 15, 20, and 25%.

Table 2: SCC mix proportion for CPA contents

Mix No.	CPA (%)	Cement (kg/m^3)	CPA (kg/m^3)	Fine Aggregates (kg/m^3)	Coarse Aggregates (kg/m^3)	Water (kg/m^3)	Super-plasticizer (kg/m^3)
MCP-00	0	500	0	805.46	884.56	200	7
MCP-01	5	475	25	805.46	884.56	200	7
MCP-02	10	450	50	805.46	884.56	200	7
MCP-03	15	425	75	805.46	884.56	200	7
MCP-04	20	400	100	805.46	884.56	200	7
MCP-05	25	375	125	805.46	884.56	200	7

Table 3: SCC Mix Proportion for CPA + RHA Blends

Mix No.	CPA (%)	RHA (%)	Cement (kg/m^3)	CPA (kg/m^3)	RHA (kg/m^3)	Fine Aggregates (kg/m^3)	Coarse Aggregates (kg/m^3)	Water (kg/m^3)	Super-plasticizer (kg/m^3)
MCR-00	0	0	500	0	0	805.46	884.56	200	7
MCR-01	0	10	450	0	50	805.46	884.56	200	7
MCR-02	5	10	425	25	50	805.46	884.56	200	7
MCR-03	10	10	400	50	50	805.46	884.56	200	7
MCR-04	15	10	375	75	50	805.46	884.56	200	7

2.2.1 Fresh properties of CPA SCC

The slump flow test was carried out in line with BS EN 12350-8 (2010) in order to evaluate the horizontal free flow of SCC in the absence of obstructions. It was performed on SCC with 0, 5, 10, 15, 20, and 25% CPA substitution of cement using a cone mould of 100 mm x 200 mm x 300 mm. The mould was cleaned, placed in the center of a plate, and then filled to the top with SCC. It was then lifted vertically while the SCC was allowed to freely flow out until it stopped spreading. The diameters (d1 and d2) of the SCC were measured in two (2) perpendicular directions, and the slump flow was calculated using Equation 1. The experiment was then performed with CPA SCC combined with 10% RHA, which is an established optimum replacement level for RHA content as stated in the literature.

$$Slump\ flow\ (mm) = \frac{d_1 + d_2}{2} \qquad (1)$$

where, d_1 and d_2 are the diameters of flow at two different diagonals (mm). Similarly, the passing ability test was performed in accordance with BS EN 12350-10 (2010) utilizing the L-Box test technique for SCC containing 0, 5, 10, 15, 20, and 25% cement replacement with CPA and CPA blended with 10% RHA optimal. The vertical L-Box's section was filled with SCC and allowed to rest for one (1) minute before the gate was lifted to allow the concrete to flow into the horizontal area. Equation 2 was used to calculate the passing ability, commonly known as the blocking ratio.

$$Blocking\ ratio = \frac{H_2}{H_1} \qquad (2)$$

where, H_1 and H_2 are the heights of concrete at each end of horizontal section of L-Box. Also, the segregation resistance test was carried out in accordance with BS EN 12350-11 (2010) utilizing the sieve stability test technique for SCC containing 0, 5, 10, 15, 20, and 25% cement replacement with CPA and CPA blended with 10% RHA optimal. Fresh SCC was placed in a container and left to stand for 15 minutes to allow for internal segregation. It was then poured into a 350 mm diameter 5 mm sieve and left to stand for two (2) minutes. The weight of the mortar that passed through the sieve was weighed, and the segregation resistance was determined in percentage using Equation (3).

$$Segregation\ resistance\ (\%) = \frac{W_2}{W_1} \times 100 \qquad (3)$$

where, W_1 is the Weight of concrete poured onto sieve, and W_2 is the Weight of mortar passing sieve

2.2.2 Compressive strength test

In accordance with BS EN 12390-3, compressive strength tests were performed on specimens of CPA and CPA-RHA SCC manufactured with 0, 5, 10, 15, 20, and 25% cement replacement levels, respectively (2009). In line with BS EN 12390-2, the mixture was manually mixed and cast in steel cylindrical moulds of 100 mm diameter and 200 mm length before being cured in water for 3, 7, 28, 56, and 90 days (2009). At the end of each curing regime, three samples of each mix proportion were air dried, then weighed and the weight recorded before being crushed in accordance with BS EN 12390-3 (2009) using the Avery Denison Compression Testing Machine of 2000 kN load capacity at a load rate of 0.5 kN/s and the loads at failure were recorded. Equation (4) was then used to compute the strength.

$$f_c = \frac{P}{A} \qquad (4)$$

where f_c is the compressive strength (N/mm^2), P is the crushing load (N), and A is the section area of cylinder (mm^2).

2.2.3 Splitting tensile strength test

The splitting tensile strength of CPA and RHA SCC was tested in accordance with BS EN 12390-6 (2009) using 100 mm diameter and 200 mm length cylinders on specimens made with 0, 5, 10, 15, 20, and 25% cement replacement and cured for 3, 7, 28, 56, and 90 days. A total of ninety (90) CPA and CPA-RHA specimens were produced, while three (3) samples of each curing age were removed, air-dried, and crushed, with the longitudinal axis of the cylinders placed horizontally using the Avery Denison universal testing machine with a capacity of 600kN and a load rate of 0.4 kN/s. Equation (5) was used to calculate the SCC's splitting tensile strength.

$$f_s = \frac{2P}{\pi l d} \quad (5)$$

where f_s is the splitting tensile strength (N/mm^2), P is the splitting load (N), l is the length of cylinder (mm), and d is the diameter of cylinder (mm).

2.2.4 Flexural strength test

Flexural strength tests were performed on a total of ninety (90) specimens of CPA and CPA-RHA SCC manufactured with 0, 5, 10, 15, 20, and 25% cement replacement levels, in line with BS EN 12390-3. (2009). It was then manually mixed and cast in steel prism moulds of 100 mm x 100 mm x 500 mm before being cured in water for 3, 7, 28, 56, and 90 days in line with BS EN 12390-2. (2009). Three (3) samples of each mix proportion were air dried before being tested using the two (2) point loading method in accordance with BS EN 12390-5 (2009) on an Avery Denison Compression Testing Machine with a load capacity of 600 kN and a load rate of 0.4 kN/s, and the loads at failure were recorded. Equation (6) was used to calculate the flexural strength of the concrete prism.

$$f = \frac{PL}{bd^2} \quad (6)$$

where f is the flexural strength (N/mm^2), P is the ultimate load (N), L is the length of prism (mm), d is the depth of prism (mm), and b is the width of prism (mm).

3. Results and discussion

3.1 Consistency and setting times of CPA cement paste

The consistencies of CPA cement paste varied at 0, 5, 10, 15, 20, and 25% replacement levels of cement, as shown in Fig. 2, with 30 percent at 0% CPA and 38 percent at 25% CPA. It was found that increasing the CPA concentration increases the amount of water needed. This could be related to CPA's porous structure, which creates a huge surface area, as suggested by Le (2015) when studying the behaviour of rice husk ash in self-compacting concrete. Raheem et al. (2015) and Owolabi et al. (2015) both attributed this behaviour to the CPA's increased water absorption potential.

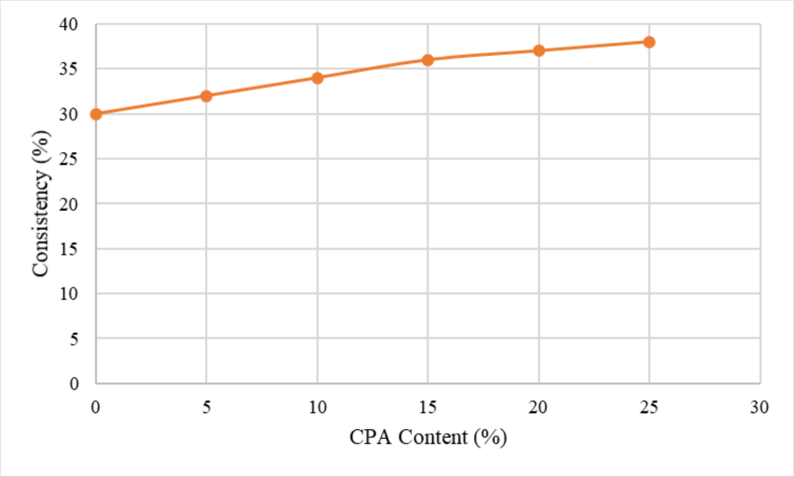

Fig. 2: Consistency of CPA-cement paste

However, the initial and final setting times of CPA-cement paste range from 70 to 175 minutes and 112 to 253 minutes, respectively, for 0 to 25% cement replacement with CPA, as shown in Fig. 3. The initial setting time of 70 minutes is consistent with the specification in BS EN 197-1 (2000), which states that it should not be less than 45 minutes. As a result, the CPA-cement paste is not susceptible to the false set problem. The initial and final setting times of CPA-cement paste increase as the CPA % increases. This is consistent with the findings of Olatokunbo et al. (2018) and could be due to the low rate of hydration in the CPA-containing paste.

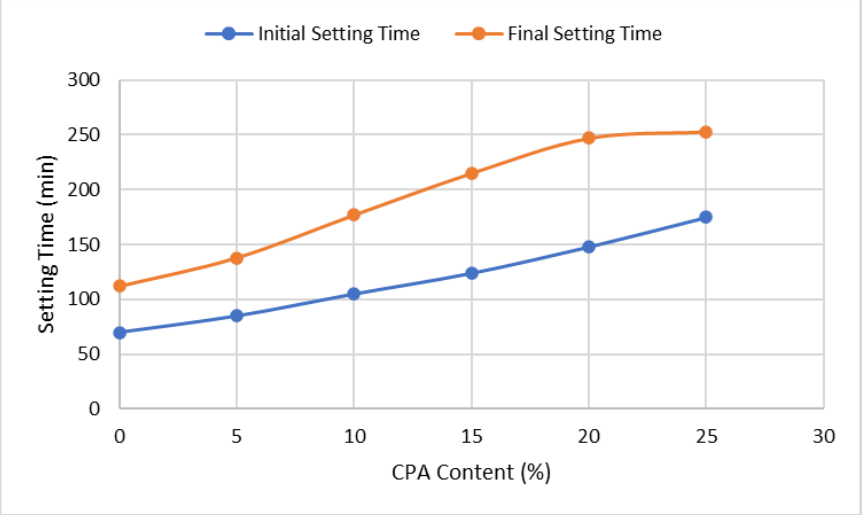

Fig. 3: Setting time of CPA-cement paste

3.2 Workability of CPA SCC

As demonstrated in Fig. 4, the slump flow for all CPA SCC mixtures reduces from 691mm to 642mm as the CPA content increases. The decrease could be attributed to the fact that CPA SCC absorbs more water as CPA concentration increases. CPA SCC mixes MC-00 (0 percent CPA), MC-01 (5 percent CPA), MC-02 (10 percent CPA), and MC-03 (15 percent CPA) met the EFNARC (2002) minimum requirement for slump flow range of 650 mm to 800 mm, while mixes for MC-04 (20 percent CPA) and MC-05 (25 percent CPA) with slump flow of 648 mm and 642 mm, respectively, fell slightly short of the 650 mm.

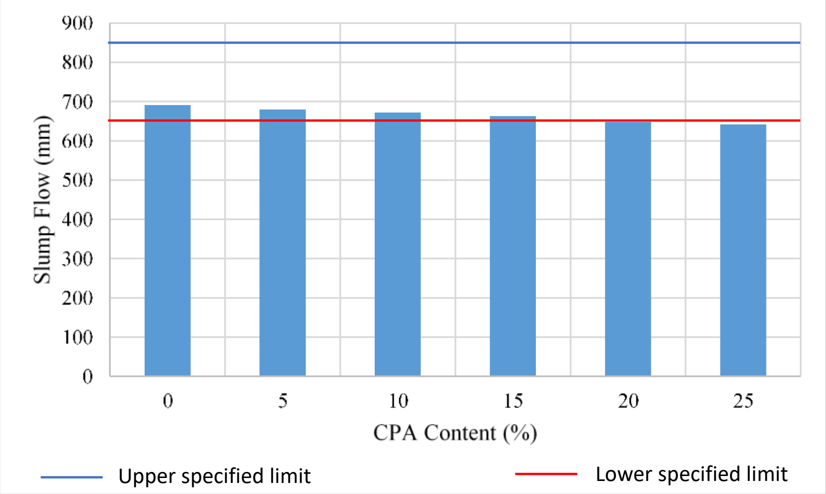

Fig. 4: Slump flow of CPA SCC

Fig. 5 shows the passing ability of CPA SCC using the L-Box approach to estimate its blocking ratio. Except for MC-04 (20 percent CPA) and MC-05 (25 percent CPA), which had blocking ratios of 0.757 and 0.692, all of the CPA SCC mixes met the EFNARC (2002) criteria for a blocking value range of 0.8 to 1.0. The drop in blocking value may be related to the increased need for water when CPA content increases. This is consistent with the findings of Le et al. (2014), who investigated the synergistic effects of rice husk ash and fly ash on the characteristics of SCC.

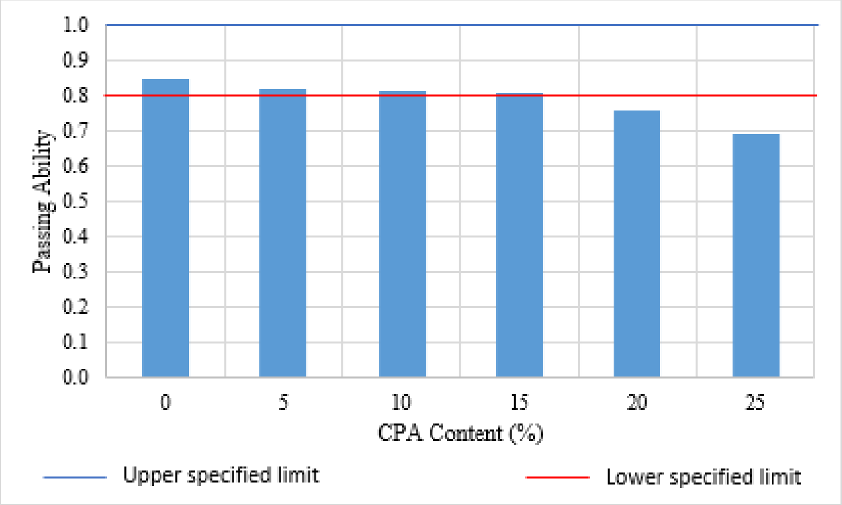

Fig. 5: Passing ability of CPA SCC

Fig. 6 also shows the segregation resistance of CPA SCC for 0, 5, 10, 15, 20, and 25% replacement levels. The segregation resistance of CPA SCC increased as the content of CPA increased, which could be attributable to a loss in consistency caused by CPA's high demand for water. However, all of the CPA SCC blends meet the EFNARC (2002) criteria of a 15% segregation resistance rating.

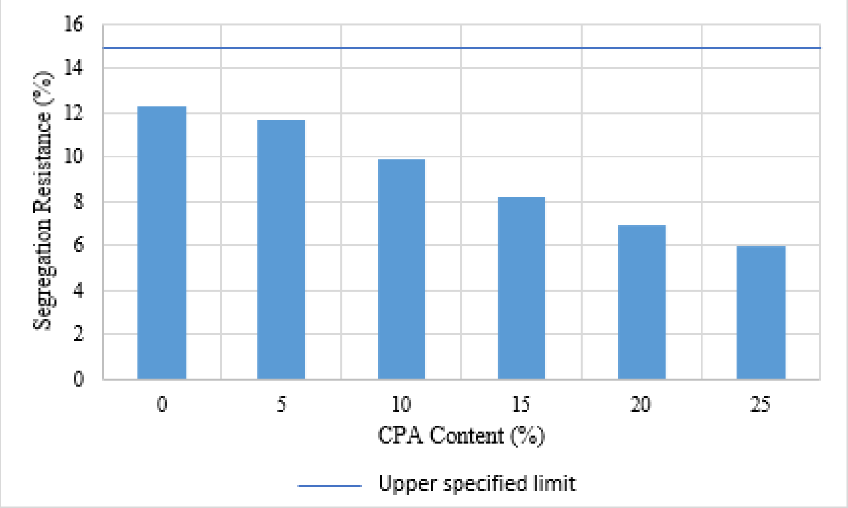

Fig. 6: Segregation resistance of CPA SCC

3.3 Compressive strength of CPA SCC

Fig. 7 depicts the compressive strength of CPA SCC in relation to curing ages of 3, 7, 28, 56, and 90 days. The strength increases with curing age at all replacement levels and decreases with increasing CPA concentration at all curing ages. The increase in strength with curing age could be attributed to the pozzolanic reaction of CPA and cement hydration. This behaviour is consistent with the findings of Ikponwosa and Olonade (2017) and Olatokunbo et al. (2018). However, when less than 5% CPA by weight of cement is applied, the compressive strength of CPA SCC at 28 days (35.6 N/mm^2) marginally exceeded the design characteristic strength (35 N/mm^2). This is comparable to the finding by Raheem et al. (2015) that CPA has the ability to contribute to 28-day strength growth when utilized at 5%. It was also discovered that at curing ages greater than 50 days, CPA SCC yields high strength (40.3 N/mm^2 – 43.7 N/mm^2) greater than the design characteristic strength for 5% and 10% replacement levels, and thus can be used in high strength requirements, as Ettu et al. (2013) reported when working with cassava waste ash.

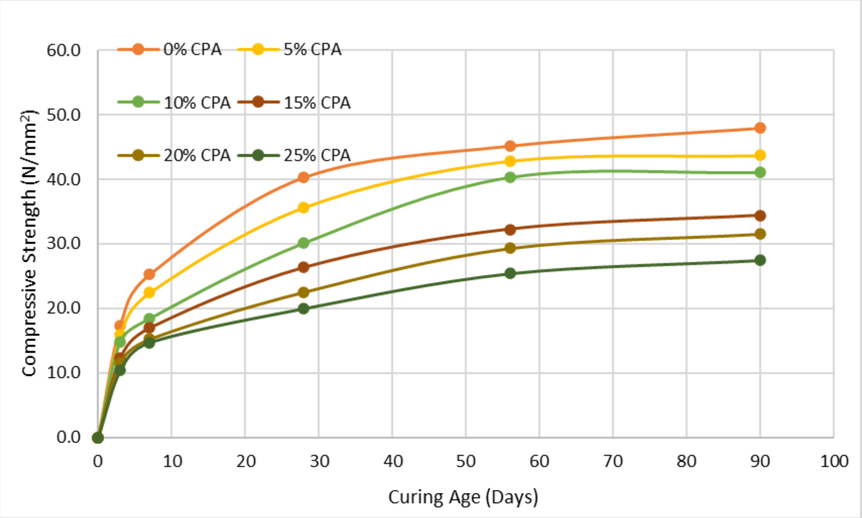

Fig. 7: Compressive strength development of CPA SCC

3.4 Splitting tensile strength of CPA SCC

As shown in Fig. 8, the splitting tensile strength of CPA SCC increases with curing age and decreases with increasing CPA concentration. This is comparable to the findings of Ogork and Uche (2014), who found that the splitting tensile strength of GSA concrete decreased as the GSA percentage increased. The reduction in splitting tensile strength could be attributed to a delay in strength development caused by delayed setting times (Oyekan and Kamiyo, 2011), whereas the increase in strength could be attributed to a modification of the bonding properties of the binders' hydrates as reported by Oyebisi et al. (2020). However, at all curing ages, the tensile strength of the CPA SCC was found to be lower than that of the control.

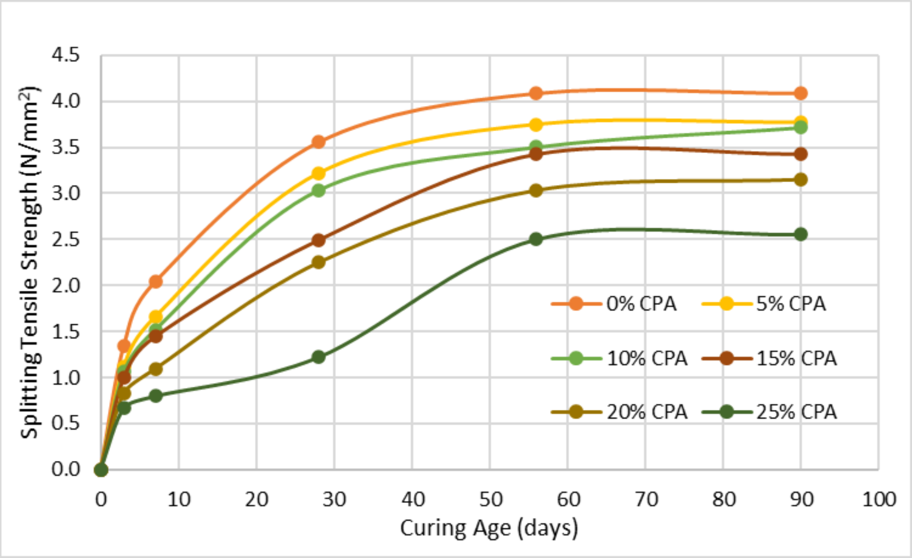

Fig. 8: Splitting tensile strength development of CPA SCC

3.5 Flexural strength of CPA SCC

The flexural strength of CPA SCC displayed in Fig. 9 shows that for all CPA mixes, the strength increases with curing age but decreases with increasing CPA concentration. This performance is consistent with Salau et al. (2012) findings. However, the flexural strength of the CPA SCC was found to be lower than the control at all curing ages and to behave similarly to the splitting tensile strength.

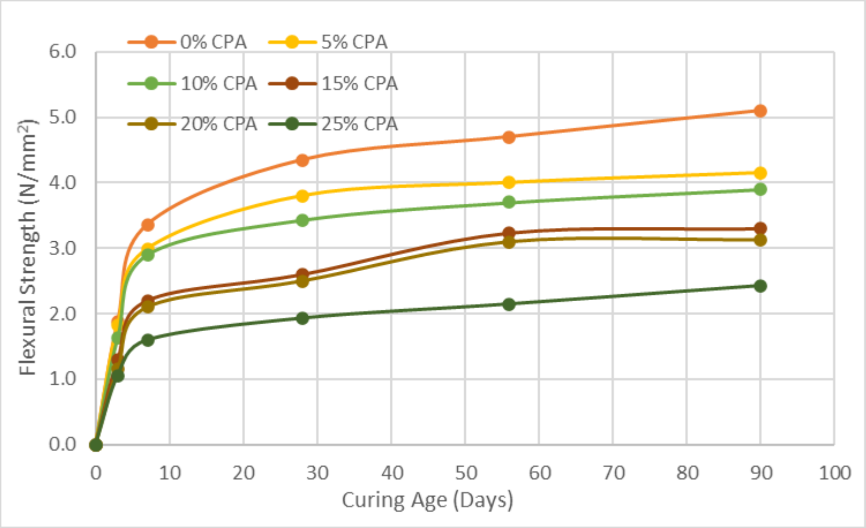

Fig. 9: Flexural strength development of CPA SCC

3.6 Consistency of cement Admixed with CPA-RHA

Fig. 10 depicts the different consistencies of CPA-RHA cement paste at 0, 5, 10, 15, 20, and 25% cement replacement levels. The consistency ranges from 30% at 0% CPA-RHA (0 percent CPA + 0% RHA) to 45 percent at 25% CPA-RHA (15 percent CPA + 10% RHA), indicating that increasing the CPA-RHA content increases the amount of water required. This could be attributed to the high porosity of both CPA and RHA, as proposed by Kartini et al. (2010) and Le (2015). It was also discovered that the water absorption of CPA-RHA paste is more than that of CPA paste with the same cement replacement amount.

This observation is comparable to that of Ogork and Uche (2014), who investigated the effect of groundnut husk ash in cement paste and mortar, and could be attributed to RHA's porous character as opposed to CPA's.

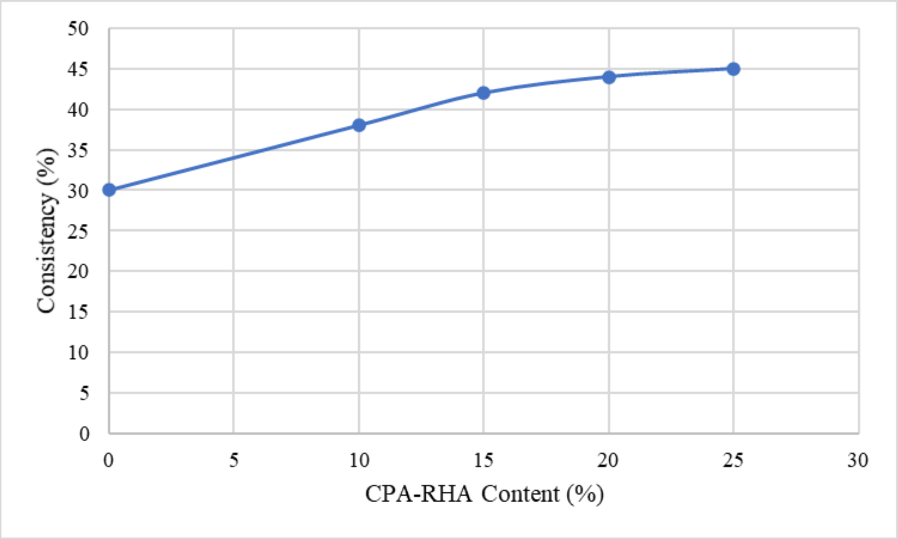

Fig. 10: Consistency test for CPA-RHA SCC

3.7 Setting times of cement admixed with CPA-RHA

The initial and final setting times of CPA-RHA cement paste, as shown in Fig. 11, rise as the amount of blended CPA-RHA increases. This behavior is comparable to the findings of Marthong (2012)'s experiment and could be attributed to the low rate of hydration in the paste containing both CPA and RHA (Dakroury and Gasser, 2008). It was also observed that both the initial and final setting times of CPA-RHA cement pastes were higher than those of the control paste, which could be due to the reaction mechanism of the blended CPA-RHA paste as also reported by Elinwa and Ejeh (2004).

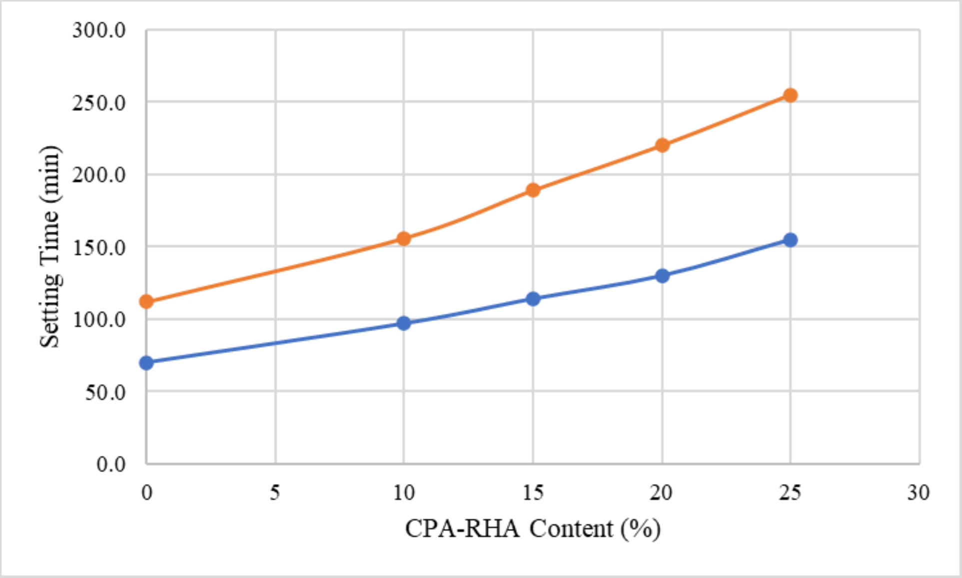

Fig. 11: Setting time for CPA-RHA SCC

3.8 Slump flow for CPA-RHA SCC

As shown in Fig. 12, the slump flow for all CPA-RHA SCC blends decreases from 691mm to 647mm as the blended CPA-RHA concentration increases. As the CPA-RHA level rises, the reduction may correspond to increased water absorption ability. It was recorded that all the blended CPA-RHA SCC mixes satisfied the minimum requirement of EFNARC (2005) for slump flow range of 650mm to 850mm with the exception of 25 % CPA-RHA (15 % CPA + 10 % RHA) with slump flow of 647mm which is slightly below the EFNARC (2005) minimum requirement. It was also discovered that the CPA-RHA SCC slump flow is slightly better than the CPA SCC slump flow. This enhancement could be attributed to RHA's dispersing impact on cement particles, as observed by Habeeb and Fayyadh (2009).

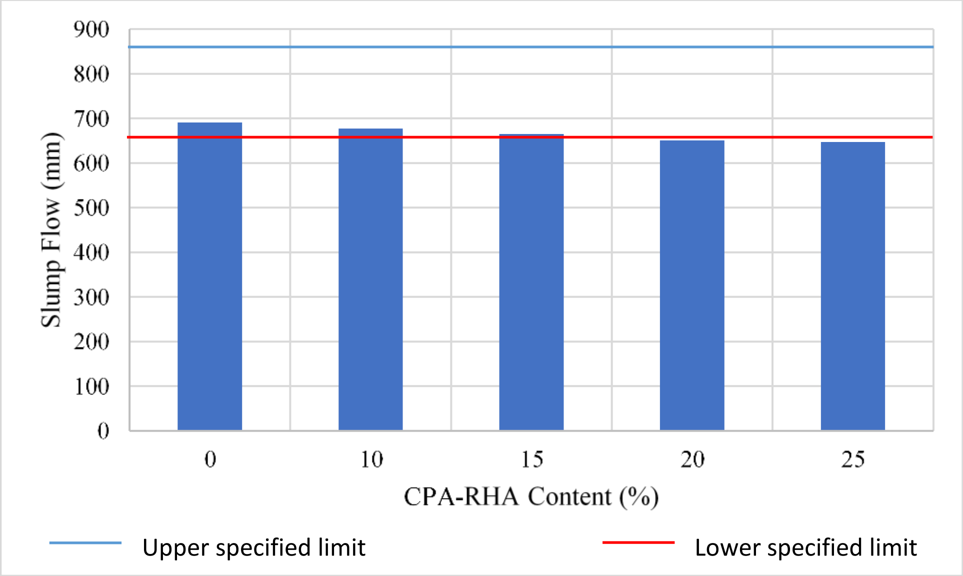

Fig. 12: Slump flow against CPA-RHA content

3.9 Passing ability (L-Box) for CPA-RHA SCC

Fig. 13 depicts the results of the passing ability of CPA SCC combined with RHA utilizing the L-Box approach. This decreases significantly when the percentage of CPA-RHA composition increases due to increased water demand, as indicated by Van et al (2013). It is worth mentioning that just 25% CPA-RHA (15% CPA + 10% RHA) SCC is somewhat below the EFNARC (2005) standard for a blocking value range of 0.8 to 1.0 with a blocking ratio of 0.766.

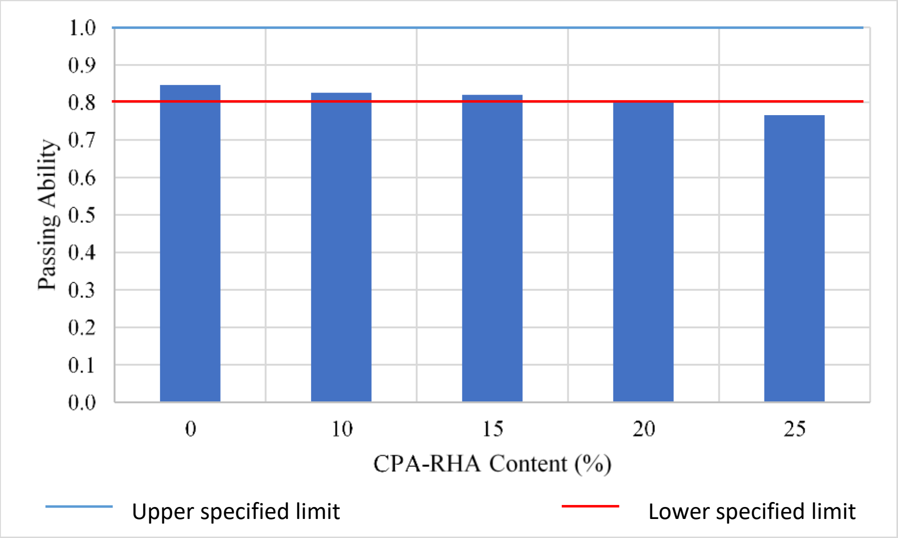

Fig. 13: Passing ability against CPA-RHA content

3.10 Segregation resistance for CPA-RHA SCC

As shown in Fig. 14, the segregation resistance of CPA-RHA SCC increases as the CPA-RHA content increases for all replacement levels. The increase in resistance could be due to a strong demand for CPA-water RHA's absorption capability. However, all of the CPA-RHA SCC mixtures meet the EFNARC (2005) criteria of a 15% segregation resistance rating.

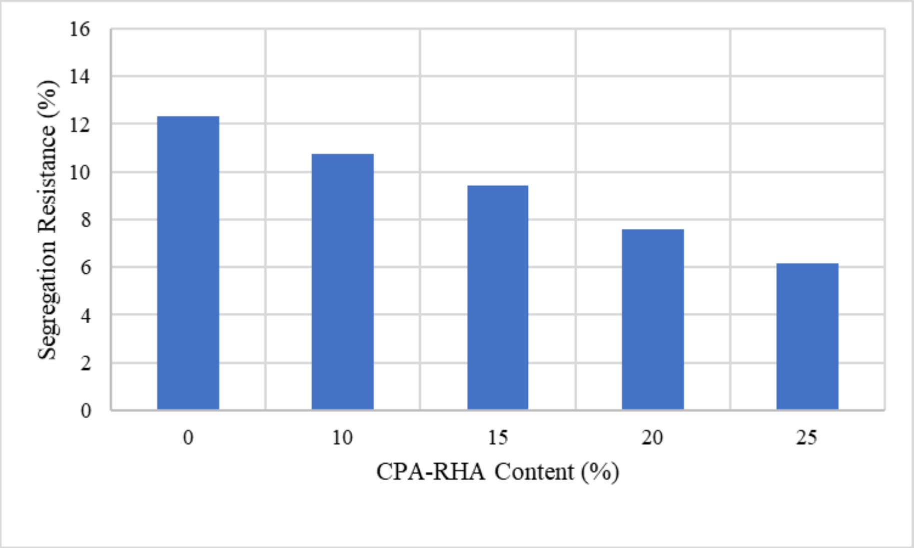

Fig. 14: Segregation resistance against CPA-RHA content

3.11 Compressive strength of CPA-RHA SCC

The compressive strength of CPA-RHA SCC, as shown in Fig. 15, increases with curing age and may be related to cement hydration, as suggested by Owolabi et al. (2015). The strength likewise increases with 10% CPA-RHA (0% CPA + 10% RHA) over the control samples and then decreases with increased cement content replacement. This increase in strength could be attributed to the stronger pozzolanic reaction of RHA content, as well as a superior filler effect than

CPA. This is comparable to the conclusions reached by Ogork and Uche (2014) while dealing with groundnut husk waste. It should be noted that the compressive strength (35 N/mm^2) exceeded the design characteristics strength (35 N/mm^2) at curing ages of 28 days and higher with up to 15% CPA-RHA (5 percent CPA + 10% RHA) content. This is also shown with 25 percent CPA-RHA (15 percent CPA + 10% RHA) cure ages longer than 56 days. This property is equivalent to that discovered by Ettu et al. (2013), indicating that CPA concrete can be employed in high strength needs at curing ages larger than 50 days.

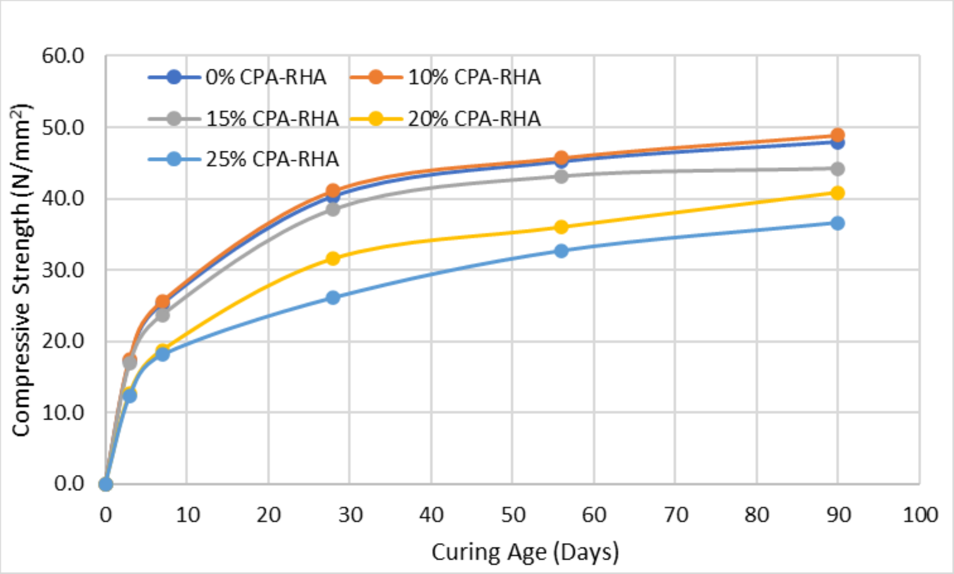

Fig. 15: Compressive strength development of CPA-RHA SCC

3.12 Splitting tensile strength of CPA-RHA SCC

The splitting tensile strength of CPA-RHA SCC illustrated in Fig. 16 increases and slightly exceeds the control samples with increasing CPA-RHA content up to 10% CPA-RHA (0% CPA + 10% RHA), but reduces after that at 15% CPA-RHA (5% CPA + 10% RHA) substitution of cement for all curing ages. This is similar to the findings of Khassaf et al. (2014a,b), who saw an increase in splitting tensile strength at 10% cement replacement with RHA but at 28 days of curing age. The strength of CPA-RHA SCC was found to be higher than that of CPA SCC with the same percentage replacement of cement, which could be attributed to increased pozzolanic reaction of RHA component, as reported by Habeeb and Fayyadh (2009). It was also discovered that after 56 days of curing age and above, the strength at 15% CPA-RHA (50% CPA+10% RHA) replacement began to equal the control (Khassaf et al., 2014a,b).

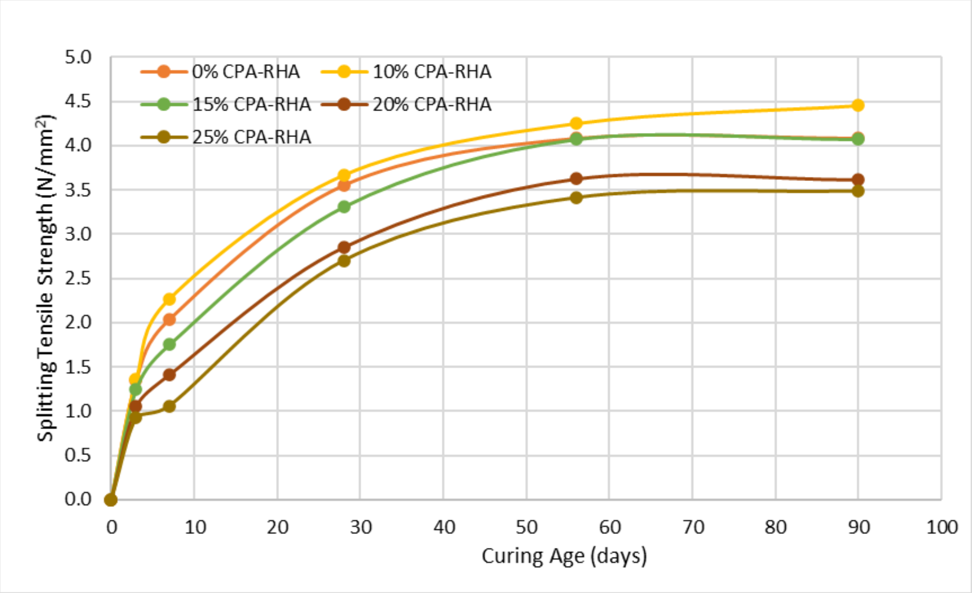

Fig. 16: Splitting tensile strength development of CPA-RHA SCC

3.13 Flexural strength of CPA-RHA SCC

Fig. 17 depicts the flexural strength of CPA-RHA SCC, which shows that the strength increases with curing age. The strength increases with increasing CPA-RHA content at 10% CPA-RHA (0% CPA + 10% RHA), although it decreases slightly at the early curing age of 3 days. This behaviour is consistent with Vinothan and Baskar's findings (2015). The flexural strength of the blended CPA-RHA SCC is higher than that of CPA SCC, similar to the splitting tensile strength. This improvement could be attributed to the finer RHA particles' enhanced pozzolanic reaction and packing ability, as indicated by Ogork and Uche (2014) and Foong et al. (2015).

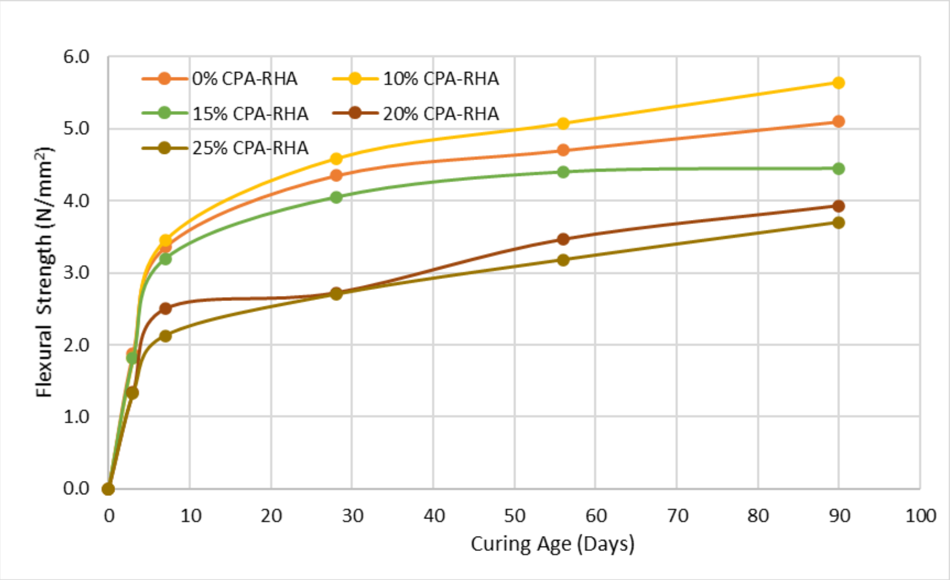

Fig. 17: Flexural strength development of CPA-RHA SCC

4. Conclusion

From the study, the following conclusion and observations were drawn.

i. Despite the fact that CPA is a poor pozzolana, both CPA and RHA meet the basic requirements for usage in SCC.
ii. The compressive, splitting, and flexural strength of CPA SCC decreased as CPA content increased, with 5% CPA content regarded as the ideal cement replacement for grade 35 CPA SCC for 28 days and above compressive strength.
iii. As RHA blends with CPA for no more than 10% CPA-RHA replacement, the compressive, splitting, and flexural strength of CPA-RHA SCC increases.

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