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Characterization of Calcined Clay Blended Self Compacting Concrete-Correlation between Super-plasticizer dosage and Self-Compacting Concrete Properties

Caracterizarea betonului autocompactant amestecat cu argilă calcinată - corelația dintre doza de super-plastifiant și proprietățile betonului autocompactant

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Abstract. *Sustainability in the construction industry is essential to economic development and can be achieved by the use of locally available construction materials. This research work, thus, uses locally available materials –calcined clay and Sandcrete SPR-300 superplasticizer in the production of Self Compacting Concrete (SCC) by investigating the correlation between the superplasticizer dosage and the fresh and hardened states properties of a grade 30 SCC made by incorporating a Calcined Clay (CC) – Portland Limestone Cement (PLC) blend as the cementitious material at 15% replacement of PLC with CC and using CC as filler. The superplasticizer dosage was varied from 0.0 to 3.0% by weight of cementitious material and the fresh state properties - measured using slump flow tests, v-funnel time test and L-box test – as well as strength parameters investigated. The result shows a positive correlation between the increased dosage of the superplasticizer and the fresh and hardened states properties of the SCC up to 2% dosage of the SCC. The* J_{Spread}*,* t_{500J}*, Slump flow, L-box* H_2/H_1 *ratio and strength, all increases with SP dosage while the V-funnel flow decreased with SP dosage. Overall, SP ratio of 1.5 and 2.0% by mass of cementitious material can be used in improving the properties of SCC produced using calcined clay both as filler and SCM. However, because of the volume of clay used and the nature thereof, the target strength could not be reached. It is therefore recommended that SP dosage of Sandcrete SPR-300 of between 1.5 and 2.0% be used with calcined clay as SCM but different filler, like limestone powder, be used.*
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Keywords: Calcined Clay, Compressive Strength, Fresh-state Properties of SCC, Self-Compacting Concrete, Superplasticizer dosage.

1. Introduction

Concrete is the life-wire of the construction industry and it has been described as the most utilized construction material in the world [1]. Globally, the annual concrete consumption stands at over ten billion metric tons and is the second most utilized material on earth, second only to water [2] Thus, the importance of this material to humanity cannot be overemphasized. Basically, concrete is a heterogeneous material consisting of a binder (Cement), aggregates (Fine and Coarse), water and sometimes some mineral admixtures and is characterized by its strength at 28 days and its durability. Concrete is said to be durable if it can maintain a reasonable amount of its mechanical properties, especially its compressive strength, over a period of time known as its service life. Other properties of concrete considered under durability include its resistance to chemical attacks, freezing and thawing, cracking, corrosion resistance of the embedded reinforcement, etc. [3].

To ensure that concrete satisfies its intended use during its lifetime as well as satisfy the evolving needs of the construction industry, various improved forms of this product have been invented/ developed, especially in the last century that architects and construction engineers have ventured into otherwise impossible ambitious designs and constructions. One of such revolutionary concretes is Self-Compacting Concrete (SCC) also known as self-consolidating concrete. [4] defines Self-consolidating concrete (SCC) as highly flowable, non-segregating concrete that can spread into place, fill the formwork, and encapsulate the reinforcement without any mechanical consolidation. In general, SCC is concrete made with conventional concrete materials and, in some cases, with a viscosity-modifying admixture (VMA). SCC has also been described as self-compacting concrete, self-placing concrete, and self-leveling concrete, which all are subsets of SCC. SCC involves the use of large amounts of secondary cementatious materials (SCM) and fillers which reduces the cost of concrete production. Also, the use of SCMs optimizes two of the three most important fresh properties of SCC, namely segregation resistance and flowability.

Despite the many advantages inherent in the use of SCC, there is no limit to improvements that can be brought about on this very important construction material. For instance, when compared to NVC, SCC has different mix composition due to the presence of high quantities of fine particles and paste but lower coarse aggregate content which can lead to a change in the pore structure of SCC and alter some of its properties like its fracture behavior [5,6]. Thus, concerns are raised about the fracture behavior of SCC because the lower coarse aggregate content can lower its energy absorption capacity and hence its ductility [7]. Other properties of SCC that can be improved upon include its strength, pore characteristics and durability characteristics. However, the properties of SCC in the hardened state are mostly influenced by its fresh state properties, which are a function of the rheology of the SCC [8]. The rheology of SCC and its workability is in turn affected by the use of admixtures like super-plasticizers (SP) and viscosity modifying admixtures (VMA) [9]. Thus, research is ever ongoing aimed at improving the properties of SCC at the fresh and also hardened state by either altering the mix composition of its ingredients, incorporating new environmentally friendly materials into SCC to produce a more sustainable SCC.

This research investigates the effect of varying the quantity of a local super-plasticizer, SANDCRETE SPR-300, on the fresh and hardened state properties of a Calcined clay blended Self-compacting concrete.

Self-compacting Concrete is concrete that can flow under its own weight alone without external vibration. [10] states that SCC should not only be able to flow and compact under its own self weight but also be able to fill all parts of the duct, reinforcements, etc. and still maintain its homogeneity. It can thus be inferred that a good SCC must meet the criteria of passing ability, flowability and segregation resistance.

Flowability refers to the ability of SCC to flow under its own weight and fill all parts of the formwork without any form of external vibration. This property is sometimes referred to as the filling ability and basically has to do with the deformability of SCC. There are two distinct aspects of deformability, namely; the deformation capacity - which is the maximum ability of SCC to deform and it depends on the yield stress - and the deformation velocity; which is the time taken from the start to the end of flow of SCC. [11] citing Khayat & Tangermsirikul (2000) states that the deformation capacity of SCC can be increased by lowering the inter-particle friction between the solid particles.

Passing ability is the ability of SCC to pass through heavy reinforcing steel bars without the blocking and separation of its particles and at the same time maintaining the suspension of coarse particles in the Cement Matrix. The passing ability of SCC is affected mostly by the risk of blocking, which depends mainly on the size, shape and content of the coarse aggregates in the concrete, as well as the paste volume (Aggarwal et al. 2008). The yield stress of concrete has a far greater effect on its passing ability than its plastic viscosity.

Segregation resistance describes the ability of SCC to maintain homogeneity without separation of its larger constituents. Segregation can occur between water and solid particles in the SCC, paste and aggregates and between mortar and coarse aggregates in both the static and flowing states. It is known as dynamic segregation if it occurs during placing of SCC and static segregation if it happens after placement of concrete [12]. The resistance of SCC to segregation depends largely on the viscosity of the SCC [13]

The flowability and filling/ passing ability of SCC are key properties of SCC in the fresh state and are greatly influenced by the cement paste properties [14]. The use of super-plasticizer helps to ensure that these workability properties are achieved without compromising the segregation resistance of SCC. [15] stipulates the SP dosage as a percentage of the cementitious material content but the exact quantity is most times determined on a trial-and-error basis.

Various researchers have investigated the relationship between SP dosage and different properties of SCC, the most recent being [16] who studied the rheological properties of modified self-compacting cementitious paste and concluded that the fresh state properties impact on the properties of SCC in the hardened state. [17] studied the correlation between rheology and strength when SP dosage is varied, while [18] studied the combined effect of water-powder ratio and SP dosage on the Rheology and strength of SCC. [19-20] variously studied the effect of SP dosage and mixing time on rheology and strength of SCC. All the researchers were unanimous on the correlation between rheology of SCC and the hardened state properties as well as the influence of SP dosage.

2.0 Materials and Methods

2.1 Materials

Portland Limestone Cement, grade 42.5N was used in the and tests were carried out to determine its properties in accordance with the provisions of BS 12 (1991).

The grading and particle shapes of fine aggregate are significant factors in the production of SCC. Thus, the aggregates were carefully chosen to fit into the specifications for aggregates for SCC. Consequently, River sand from river Benue and crushed rocks of maximum particle size 10mm was used as fine and coarse aggregates respectively. The aggregates were characterized at the Civil engineering laboratory of the Joseph Saawuan Tarka University Makurdi in accordance with the provisions of BS 812 (1985) and ASTM C 127 and 136.

Super plasticizer (polycarboxylic fiber) by the trade name of Sandcrete SPR-300, was used for this study, manufactured by WAFA group of companies. The specific gravity, pH and chloride content of the SP is 1.08, 6.5 and less than 0.1% respectively.

2.2 Fresh state properties of Self-Compacting Concrete

The slump flow tests were carried out to determine the flow time, time taken to reach a diameter of 500mm and the flow diameter in line with [15, 21] while the V-Funnel test was carried out in accordance with the procedures of [22].

The L box and J rings were used to determine passing and filling ability of the SCC with the procedure set out in [15, 23-24] used for the J-ring tests; while methods given in [25] were used for the L-box tests.

2.3 Permeation and Strength properties

The permeation properties of the SCC were determined in accordance with [26] and [27, 28] for sorptivity and water absorption respectively. The test for sorptivity was carried out at 28 and 56 days for each mix to evaluate the effects of the SP dosage on the rate of water absorption through interconnected capillary poles. Three numbers diameter 100mm by 50mm discs, cut from 100mm by 200mm concrete cylinder specimens, were used for each test and the average result calculated, while the water absorption test was carried out at 7, 14, 28 and 56 days to monitor the change in water absorption capacity of the SCC with changing quantities of SP. For each test, three 50mm x 50mm x 50mm cubes were used and the average value taken. The effect of varying the SP dosage on the tensile strength was determined using diameter 100mm by 200mm cylinders at 7 and 28 days in line with the provisions of [29], while the compressive strength of the SCC was determined using 100 cubic millimeters concrete cubes cured at 7, 14, 28 and 56 days in accordance with the provisions of [30].

3.0 Results and Discussions

3.1 Materials Characterization

The materials used for the study were characterized for their physical properties, oxide composition and morphological properties. Tables 1 and 2 and figs. 1 to 3 shows the result of materials characterization.

Table 1:

Tests on Materials

Property investigated	Material tested				
	PLC	CC	PLC-CC	Fine Aggregates	Coarse Aggregates
Specific gravity	3.15		-	2.60	2.40
Setting Times Initial (final)	150 (195)	-	180 (230)	-	-
Consistency (%)	30	-	31.5	-	-
Soundness(mm)	2	-	2	-	-
Moisture Content (%)	-	-	-	3.0	-
Fineness modulus	-	-	-	3.45	-
Agg. Crushing value	-	-	-	-	21.73
Agg. Impact value	-	-	-	-	24.5

Table 2:

Result of Oxide composition of PLC and CC

Oxide	CaO	Fe_2O_3	Al_2O_3	SiO_2	TiO	K_2O	Na_2O	SO_3	BaO	P_2O_5	V_2O_5	Cr_2O_3	MnO	TiO	LOI
CC	1.5	7.7	25.1	61.2	0.36	1.8	0.03	0.2	0.11	4.32	0.1	0.03	0.04	1.8	-
PLC	65.57	6.83	5.60	16.20	0.20	0.48	0.78	2.51	0.12	-	-	-	-	-	0.09

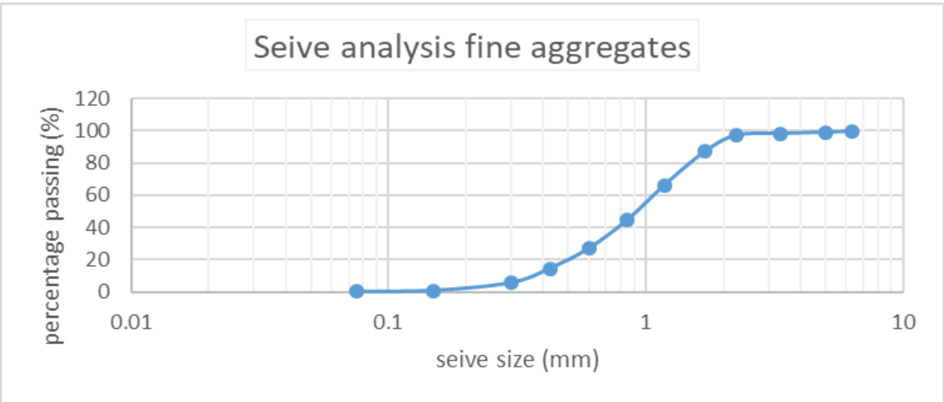

Fig. 1: Gradation curve for fine aggregates

Fig. 1 shows the gradation curve for fine aggregates. It can be seen from the curve that the sand is well graded and thus suited for SCC application.

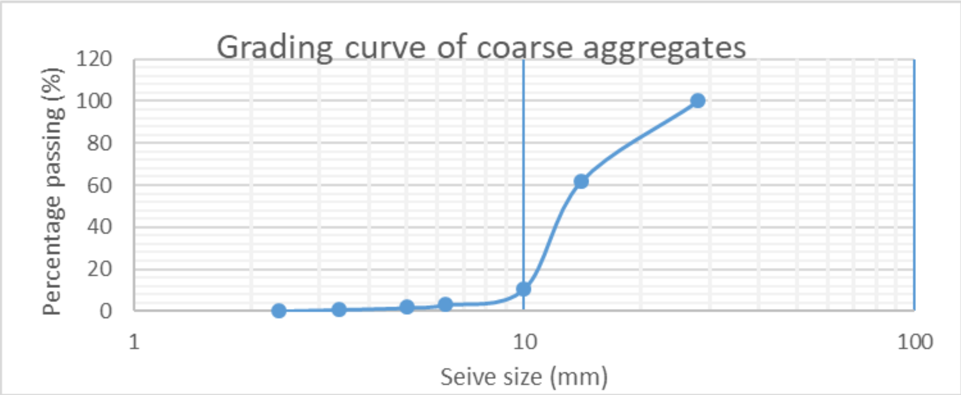

Fig. 2: Grading curve of coarse aggregates

The coarse aggregates are well graded and have a maximum aggregates size of less than 20mm as recommended in EFNARC 2005 for SCC aggregates and is thus suitable for SCC production. The result of XRF analysis presented in table 2, shows that Calcined clay contains more than 70% of SiO_2+Al_2O_3+Fe_2O_3 and so meets the ASTM C618 for a class F pozolan. The cement also contains more than 50% CaO as stipulated in BS 12.

Fig 3 gives the sieve analysis of calcined clay.

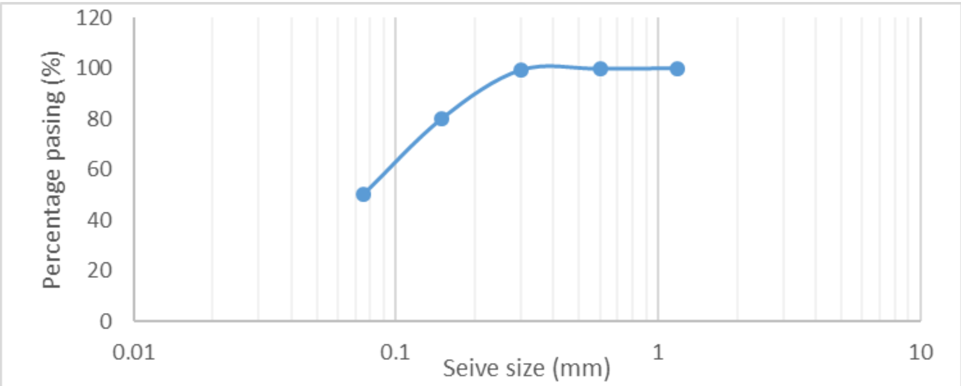

Fig. 3: Grading curve of Calcined Clay

The sieve analysis of the clay shows 50% passed through the 75µm sieve and over 99% of the clay particles are finer than 300µm. The clay particles have a large surface area for reactivity and can also fill the pore spaces between the aggregates in the concrete matrix.

The result of XRD analysis, quantitative and qualitative is presented in figures 4 and 5 respectively.

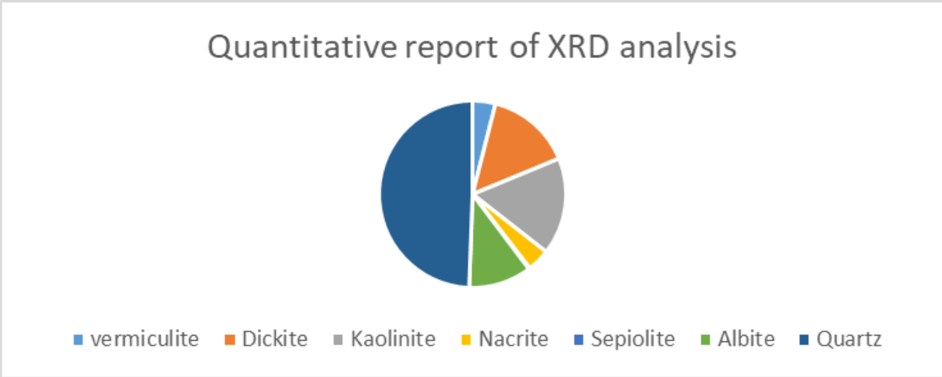

Fig. 4: XRD analysis of Calcined clay (Quantitative)

It can be seen that the CC is made up principally of quartz (50% by total mineral volume)- SiO_2 which indicates pozzolanicity and can be used as a secondary cementitious material. The result of the grading of the calcined clay also shows that more than 50% of the material is finer than 75µm and can make a good filler material.

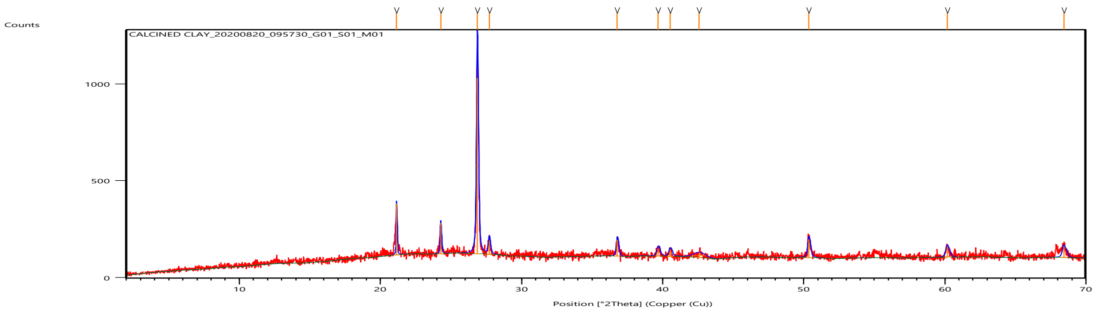

Fig. 5: Result of XRD analysis on calcined clay (Qualitative)

Fig. 6 gives the FTIR analysis of calcined clay. In the IR studies of the clays, Si-O stretching vibrations were observed at 773.3cm^{-1} (775.3 cm-^{1}); 909.5 cm^{-1} (913.2 cm^{-1}), 998.9 cm^{-1} (1028.7 cm^{-1}), for clay (and calcined clay), showing the presence of quartz (Mansor et al 2016; Manu & Dinaka 2015). A strong band at 3693.3 cm^{-1} (3697.5 cm^{-1}) and 3649.1 cm^{-1} (3623.0 cm^{-1}) indicate the possibility of the hydroxyl linkage (Messaoud et al, 2018), while the interlayer hydrogen bonding is assigned by the characteristic band of 3620 cm^{-1} (Messaoud et al, 2018). Most of the bands present in the clays shows the presence of the Kaolintes (Witkowski et al, 2018).

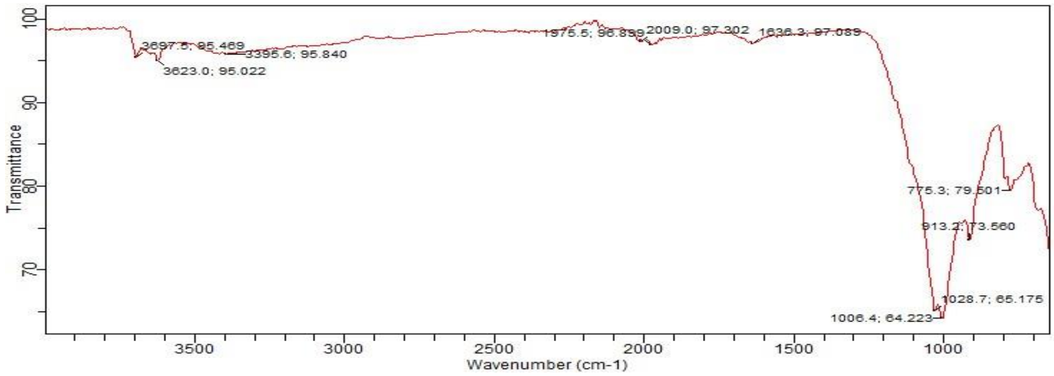

Fig. 6: FTIR Spectroscopic analysis of Calcined Clay

3.2 Mix proportioning

The mix is designed based on the principle of the plastic viscosity of the SCC mix; which was first proposed by Kharihaloo & Ghanbari (2012) and it exploits the expression for the determination of the plastic viscosity of a heterogeneous material like SCC from the known plastic viscosity of the homogenous component (in this case the cement paste). It is based on the micromechanical procedure developed by Ghanbari & Kharihaloo (2009).

Al-Rubaye (2016) and Abo-Dhaheer (2016) used this principle to develop mix design charts for SCC. The mix design chart for SCC grade 30 was used in the design of the mix to determine the quantities of the constituent materials incorporating 15% CC as SCM and using CC as the filler. The chart is presented as fig. 7 and the mix parameters are presented in table 3. The target plastic viscosity chosen is 11PaS.

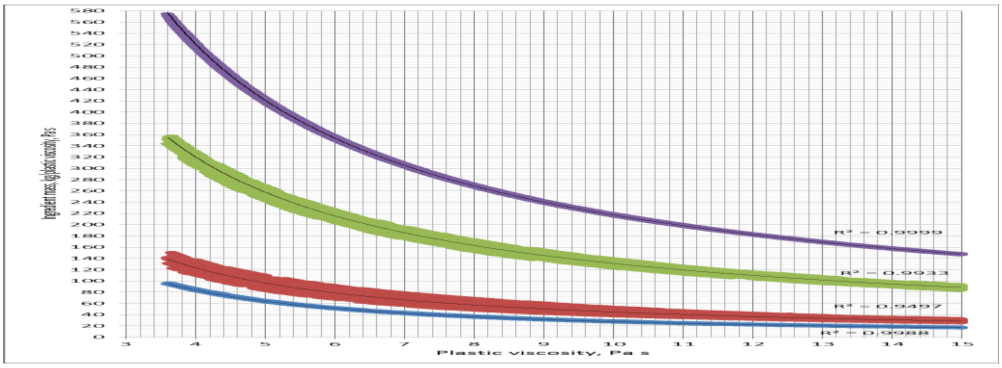

Fig 7: Design Chart for SCC grade 30 based on target plastic viscosity. (Source: Al-Rubaye, 2016)

Table 3 gives the quantities of materials calculated and used for the research.

Table 3:

Mix quantities for SCC testing

% of SP	Quantities in Kg						
	C	CC	W	SP	F	FA	CA
0	11.25	1.25	7.2	0.0	4.1	25.9	28.3
1.0	11.25	1.25	7.2	0.123	4.1	25.9	28.3
1.5	11.25	1.25	7.2	0.185	4.1	25.9	28.3
2.0	11.25	1.25	7.2	0.247	4.1	25.9	28.3
2.5	11.25	1.25	7.2	0.309	4.1	25.9	28.3
3.0	11.25	1.25	7.2	0.371	4.1	25.9	28.3

3.3 Fresh state properties

3.3.1 Flowability testing

The slump flow and V-funnel tests were used to measure the flowability of the SCC and the result is presented in table 4.

Table 4:

Flowability testing results

ID mark	Sp %	t_{500} (s)	Viscosity class	t_{flow} (s)	d_{1-} (mm)	d_{2-} (mm)	SF (mm)	SCC class	V_{funnel} time (s)
S0	0	0.44	VS1/VF1	1.36	536	538	537	-	3.86
S1	0.5	0.42	VS1/VF1	1.18	550	540	545	SF1	2.83
S2	1.0	0.60	VS1/VF1	1.29	570	575	572.5	SF1	3.24
S3	1.5	0.63	VS1/VF1	1.32	670	660	665	SF2	4.00
S4	2.0	0.53	VS1/VF1	2.10	740	740	740	SF2	3.50
S5	2.5	0.59	VS1/VF1	1.17	780	780	780	SF3	2.32
S6	3.0	0.82	VS1/VF1	1.12	810	810	810	SF3	2.06

The result shows that the mix belongs to viscosity class VS1/ VF1 based on the $t_{500\ test}$ and V_{funnel} time tests respectively for all SP dosages. However, the flow diameter shows that the mix without SP does not have the required slump flow and hence low workability. This is due to the shortage of water which could be enhanced by the use of SP since the water demand of calcined clay is high. Samples S1 to S6 all show good slump flow and workability. However samples S5 and S6 showed segregation and bleeding due to the high dosage of SP which made the workability to be too high. S3 and S4, containing 1.5 and 2.0% of SP by mass of cementitious material belongs to SCC class SF2 and showed good workability without bleeding and segregation which is an indication of low yield stress and good deformability (EFNAC 2005). The European guidelines for SCC (EGSCC 2005) states that the slump flow value gives the flowability of a fresh SCC. SF2 is suitable for most normal applications whereas class SF1 has limited applications.

3.3.2 Filling and Passing Ability tests

The L-Box and J-ring Tests are a measure of the filling and passing abilities of an SCC batch respectively and indicates how well a specific batch of SCC will flow through restricted spaces without blocking. The filling ability, determined using the L-box, gives an idea of how well an SCC mix batch can flow into and fill formwork under the action of gravity alone. The result is presented in table 5.

Table 5:

Test results for filling and passing ability

L-Box Test results							J-Ring Tests results			
ID mark	SP %	H_1	H_2	H_2/H_1	T_{200} (s)	T_{400} (s)	d_{Jx} mm	d_{Jy} mm	SF_J	Passing ability rate
S0	0.0	7.7	6.0	0.78	0.80	1.86	460	465	462.5	2
S1	0.5	7.5	6.6	0.84	0.73	1.68	500	490	495	1
S2	1.0	7.4	6.6	0.89	0.67	1.40	530	532	531	1
S3	1.5	8.2	7.6	0.93	0.68	1.04	640	640	640	0
S4	2.0	8.4	7.6	0.93	0.57	0.84	730	730	730	0
S5	2.5	8.0	7.8	0.98	0.47	0.78	770	772	771	0
S6	3.0	7.3	7.2	0.99	0.40	0.73	805	805	805	0

According to EFNARC 2005, for proper filling ability the ratio, $0.8 \leq H_2/H_1 \leq 1.0$ must hold. It can be seen from table 5 that the ratio holds true for all mixes except for S0 which contains no superplasticizer. More so all mixes met the stated criterion and visual inspection showed no signs of segregation or blockage except S0.

Similarly, from table 5, and comparing with the provisions of EFNARC 2005, sample S0, containing no SP shows noticeable to extreme blockage due to the low workability while S1 and S2 shows low passing ability with minimal to noticeable blockage and S3 to S6 sows no visible blockage due to their high workability.

3.4 Strength Characterization

Fig. 8 gives the result of compressive strength tests at 7 and 28 days.

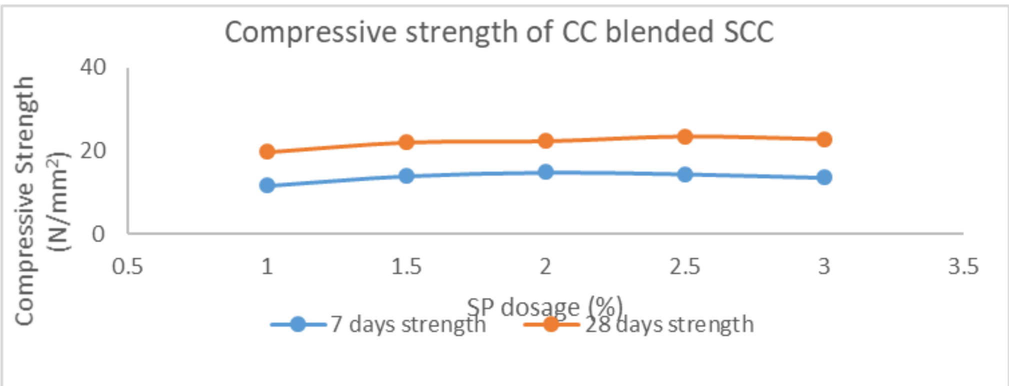

Fig 8: relationship between Compressive Strength and SP dosage

The result shows that the strength increases with curing age for all superplasticizer dosages. This is expected, as the cement hydration process is time dependent. The rate of strength increase with age, however, is higher with the SP dosage. This is because the increasing SP dosage provides for more workable concrete and hence more water is available for the hydration reaction without causing bleeding of the concrete.

3.5. Durability Characterization

The rate of ingress of water and other substances into an SCC gives a measure of the durability and is a function of the pore structure of the concrete. The two basic measures employed here are the water sorptivity that is a measure of the rate at which water ingress through interconnected pore spaces while water absorption gives a measure of the general water ingress through all kinds of pore spaces. The result of percentage reduction in water absorption is presented in fig 9 while fig. 10 shows the Sorptivity characterization.

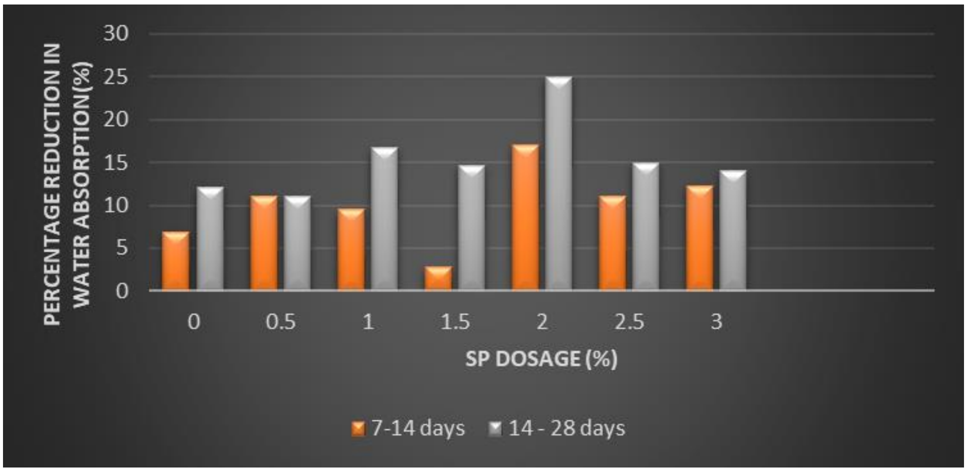

Fig. 9: Change in water absorption with age

It can be seen from fig 9 that the rate of decrease in water absorption varies with age and SP dosage with sample with 2% of SP showing the best water absorption behavior with age.

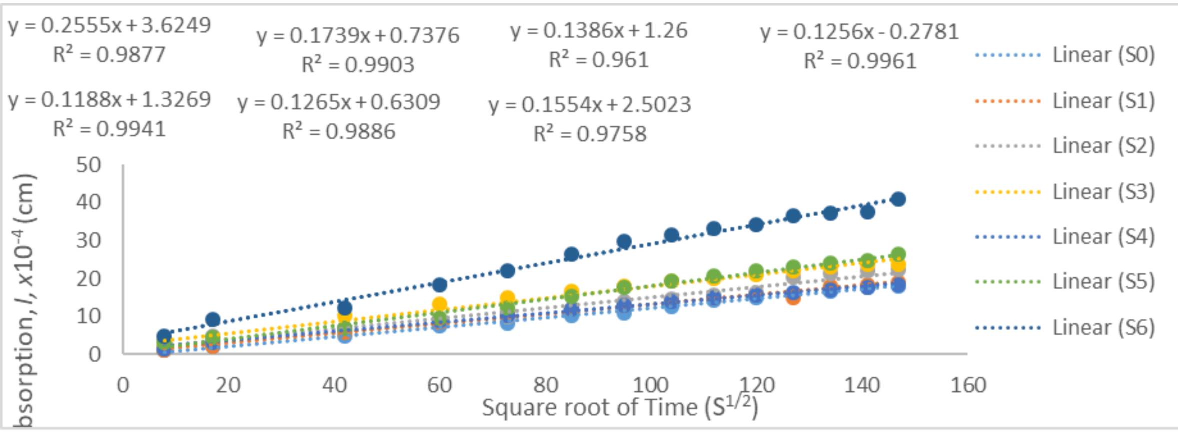

Fig 10: Sorptivity performance of CC blended SCC at 28 days curing

It can be seen that samples S3 to S5 shows better sorptivity performance, while the sample without SP (S0) shows the worst sorptivity performance at 28 days curing.

4.0 Conclusion

It is concluded from this research work that SP ratio of 1.5 and 2.0% by mass of cementitious material improves the properties of SCC produced using calcined clay both as filler and SCM. However, because of the volume of clay used and the nature thereof, the target strength could not be reached. It is therefore recommended that SP dosage of between 1.5 and 2.0% be used with calcined clay as SCM but different filler, like limestone powder, be used.

Author Contributions

The lead author (Taku Kumator) designed and supervised the entire work with the assistance of Engr Dr. B. Amartey. The experimental works were carried out by Gondo George and Eze Chinedu while Avre provided logistics and technical support.

Conflict of Interest

Declaration of conflict of interest. There is no conflict of interest

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