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EXPERIMENTAL STUDY ON STRENGTH AND DURABILITY PROPERTIES OF SELF-COMPACTING COCONUT SHELL AGGREGATE CONCRETE BLENDED WITH FLY ASH

Idowu H. Adebakin, K. Gunasekaran and R. Annadurai
Department of Civil Engineering, Faculty of Engineering and Technology SRM Institute of Science and Technology, Kattankulathur, Tamil Nadu, India
E-Mail: adebakinidowu@gmail.com

ABSTRACT

This paper reports result of performance evaluation on self-compacting coconut shell concrete (SCCSC) developed using discarded coconut shells as coarse aggregate and partial replacement of ordinary Portland cement with fly ash (FA) at 15% and 20% replacement levels. Tests carried-out on the fresh concrete such as slump flow, T_{500}, V-funnel, L-box and wet sieve segregation resistance confirmed the flowability, consistency and cohesiveness of the developed mixes. On the hardened concrete, mechanical properties tests such as density, elastic modulus, compressive, splitting tensile and flexural strengths were conducted. Furthermore, durability properties of the concrete were evaluated using water absorption, sorptivity, volume of permeable voids and rapid chloride penetration tests. Tests result showed that SCCSC1 mix with 15% FA gave an optimum compressive strength of 21.2 N/mm^{2}at 28 days and 25.1 N/mm^{2}at 90 days, while SCCSC2 with 20% FA developed compressive strength of 20.1 N/mm^2 at 28 days and 25.5 N/mm^2 at 90 days. Flexural strength, splitting tensile strength and elastic modulus for are 4.50 N/mm^2, 2.56 N/mm^2, 8490 N/mm^2 and 4.00 N/mm^2, 2.52 N/mm^2, 7480 N/mm^2 for SCCSC1 and SCCSC2 respectively. Furthermore, tests on durability properties of the developed mixes gave satisfactory results comparable to that of other lightweight concretes.

Keywords: coconut shell; aggregate; self-compacting concrete; strength; durability.

1. INTRODUCTION

Self-compacting concrete (SCC) is one of the special concrete and has the filling ability, passing ability and segregation resistance characteristics in its fresh state condition. If SCC is developed, it will flow under its own weight without vibration; will flow through heavily congested reinforcement under its own weight; and will retain homogeneity without segregation [1]. It has been reported that using SCC lead to about 60% increase in construction productivity in places like Japan and Sweden [2].

Lightweight aggregates (LWA) could be naturally sourced or artificially manufactured from industrial by-products, but apart from its attendant environmental degradation contribution, sources of these materials are getting depleted. Demand for sustainable and eco-friendly construction materials has led to some research efforts in the area of using agricultural wastes in concrete production. One of such wastes is coconut shell (CS), which has contributed largely to solid wastes in many tropical countries. Coconut is widely cultivated in more than 93 countries in the world, with Asia contributing to more than 80% of the world supply [3]. CS is usually discarded as solid waste after the nut is scraped. It has been estimated that coconut shells constitute more than 60% of the domestic waste volume in India with its attendant disposal challenges for municipal authorities [3]. When CS is crushed into small sizes, it could be used as LWA in the production of lightweight concrete (LWC). It has the dual advantage of reduction in the cost of construction material and also lead to cleaner environment. Though, utilization of CS in the production of LWC is a relatively new field, but few research outputs available has posted it as a novel idea with strength and durability properties within the acceptable standard recommendations. Reports of some research works has shown that normal concrete strength is possible using CS as replacement of conventional coarse aggregate in normally vibrated concrete [4-9]. Therefore, in this study an effort is made to establish SCC using CS as coarse aggregate. For comprehensive evaluation, mechanical and durability properties of the developed SCC using CS as aggregate were studied and reported. For comparative study, SCC using conventional concrete (CC) constituents as well was developed.

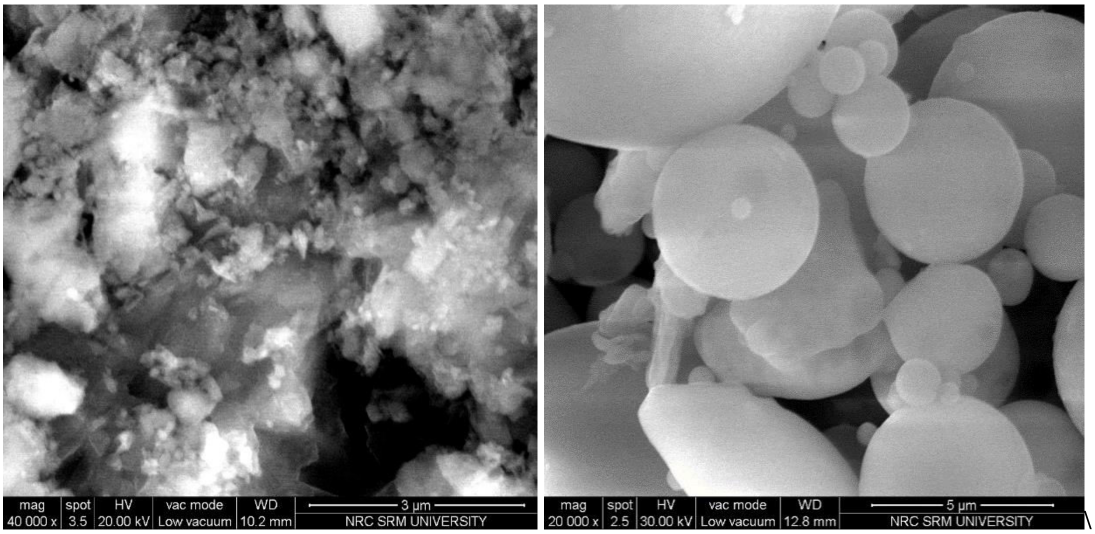
2. MATERIALS AND METHOD

2.1 Materials

Ordinary Portland cement (OPC) conforming to theIS12269:1987 [10] and class 'F' fly ash conforming to IS 3812:2003 [11] were used as binders throughout this study. Chemical compositions of these materials are presented in Table 1and Figures 1a and 1b illustrates the scanning electron microscope (SEM) images of OPC and fly ash respectively.

Table-1. Chemical properties of OPC and Fly ash.

Composition (% by mass)	**OPC** (53 Grade)	**Fly Ash** (Class F)
SiO_2	21.0	64.03
Al_2O_3	5.1	15.50
Fe_2O_3	3.1	6.50
MgO	2.4	3.00
CaO	64.1	4.62
Na_2O	0.3	-
K_2O	0.7	-
SO_3	2.2	-
Loss on ignition	0.6	4.35



(a) (b)

Figure-1. SEM micrograph (a) OPC (b) Fly ash.

Type 'F' high range water reducing admixture, commercially named as Conplast SP430 conforming to specifications in IS 9103:1999 [12] was used as super plasticizer (SP). River sand of maximum size 4.75 mm, obtained from local river and conforming to grading zone III as specified in IS 383:1970 [13] was used as fine aggregates. For coarse aggregates, raw coconut shells (Figure-2a) were mechanically crushed to required sizes as shown in Figure-2b. The edges of the crushed CS were rough and spiky which enhances bonding as can be seen in Figure-2c. Because CS is flaky in nature, maximum size used was restricted to 12. 5mm as recommended [3], and the same size was also selected for conventional coarse aggregate for comparative study. Basic physical properties of the aggregates used in this study are given Table-2. Potable water available in the University campus was used for mixing and curing of concrete elements used in this study.

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(a) (b) (c)

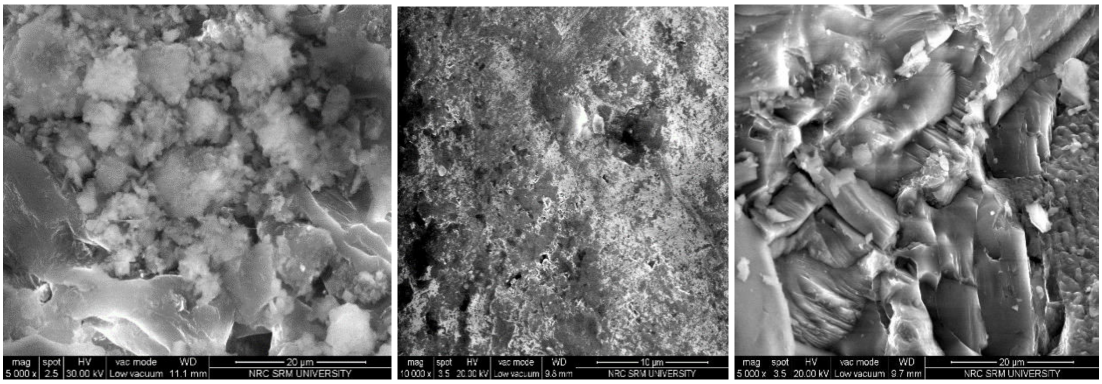
Figure-2. (a) RawCS (b) Crushed CS (c) Scaling of CS.

Table-2. Basic physical properties of aggregates used.

Physical and mechanical properties	Conventional coarse aggregate	Coconut shell	River sand
Maximum size (mm)	12.50	12.50	4.75
Water absorption (%)	0.27	24.00	-
Specific gravity	2.67	1.14	2.61
Fineness Modulus	6.77	6.54	3.72
Bulk density (kg/m^3)	1625	650	1700
Crushing value (%)	20.44	2.56	-
Impact value (%)	16.50	4.60	-

2.2 Mix proportions

The constituents of all the mixes were proportioned based on principle recommended by EFNARC [14]. Because of the high water absorption capacity of coconut shell, CS was used in saturated surface dry (SSD) condition. Figure-3 illustrates the SEM images of CS at SSD condition, conventional coarse aggregate and sand used in this study. Total powder content used for the self-compacting coconut shell concrete (SCCSC) was 510kg/m^{3}while that of self-compacting conventional concrete (SCCC), which served as control, was 450kg/m^3. Water/powder ratio of 0.33 and the super plasticizers (SP) of 1.75% of total powder content were used throughout this research and these results were arrived at after several trials. The details of the mix proportions used in this study are presented in Table-3.



(a) (b) (c)

Figure-3. SEM micrograph of (a) CS at SSD condition (b) fine aggregate (c) coarse aggregate.

Table-3. Mix proportions used.

Mix type	Cement (kg/m^3)	Sand (kg/m^3)	CA (kg/m^3)	CS (kg/m^3)	FA (%)	FA (kg/m^3)	w/b	Water (kg/m^3)	SP %
SCCC	293	450	650	-	35	157	0.33	148.5	1.75
SCCSC1	433.5	510	-	260	15	76.5	0.33	168.3	1.75
SCCSC2	408	510	-	260	20	102	0.33	168.3	1.75

CA- Coarse aggregate, CS- Coconut shell, FA- Fly ash, w/b- Water/binder, SP- Super plasticiser.

To satisfy the criteria of structural lightweight concrete as per ASTM C 330 [15], minimum 28 day compressive strength should be greater than 17 N/mm^2; hence in this study it was targeted to develop SCC with minimum compressive strength of 20 N/mm^2. Because of its low bulk density and size used, CSA content was fixed at 40% of the solid volume, while fine aggregate content was fixed at 50% of the mortar volume. After the trail mixes, for SCCC, 35 % replacement of OPC with fly ash (FA) was used. Similarly, for SCCSC, two mix ratios (SCCSC1) were selected with 15 % replacement of FA for OPC and (SCCSC2) with 20 % replacement of FA for OPC. In all the cases, w/b ratio used was 0.33 and the SP used was 1.75 %.

3. EXPERIMENTS PROGRAM

Significant mechanical properties such as density, compressive strength, splitting tensile, flexural strength and elastic modulus were studied. Durability properties such as volume of permeable voids (VPV), sorptivity, water permeability / absorption and rapid chloride penetrability test (RCPT) were conducted at concrete age of 7, 28, 56 and 90 days.

3.1 Tests for SCC

With the EFNARC committee recommended procedure as guide [14], the self-compacting properties of the mixtures were evaluated using slump flow and T_{500}, V-funnel, L-box and wet sieve segregation resistance tests (Figure-4). Procedures mix design and test results had been reported in earlier publication [16].

(a)

(b)

Figure-4. (a) Slump flow test (b) L-box test.

3.2 Mechanical properties

For compressive strength tests, 100 mm cubic concrete specimen in accordance to IS 516 [17] were prepared and tested at 7, 28, 56 and 90 days.3 days test was not done because specimens were not hardened enough for testing due to the addition of FA. Splitting tensile tests were done on 100 × 200 mm cylinder following the procedure in ASTM C 496-90 [18], while a four-point bending tests were also performed on 100 × 100 × 500 mm prisms according to IS 516 procedure for flexural strength. Modulus of elasticity of the specimens was determined using compressometer attached with digital indicators and using 100 × 200 mm concrete cylinder. Loading and unloading was up to 40% of the ultimate load as per ASTM C 469-02 [19]. In each case of all these tests, average of tests on three samples was selected. Figure-5 show test procedures for some mechanical properties.

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(a) (b) (c)

Figure-5. (a) Flexural strength test; (b) Splitting tensile test; (c) Static elastic modulus test.

3.3 Durability properties

Under normal condition, concrete is generally durable, but for reinforced concrete, the percolation of moisture through concrete pores will facilitate the corrosion of steel, leading to an increase in the volume of steel, then cracking and spalling of concrete cover. Therefore, this study also investigates the durability performance of the developed SCC mixes using some standard methods.

For VPV and absorption test, oven-drying method suggested by American Standards ASTM C 642-97 was followed [20]. For this test, initially, cylinder specimens of size having diameter 100 mm and height 200 mm were cast. These specimens were kept under water curing for 28 days. After 28 days, from each cylinder specimen, a size of 100 mm diameter and 100 mm height was cut from its center and used for the test (Figure-6a). For sorptivity test, method suggested by American Standards ASTM C1585 [21] was followed. To conduct this test, from each cylinder sample, three specimen having size 100 mm diameter and 50 mm thickness were cut from its centre and used for the test. Before the start of this test, these specimens were preconditioned by allowing the specimens at 50°C (Figure-6b) continuously for seven days and then cooled in a container sealed for the duration of three days. At the time of testing, these specimens were sealed on their side faces with insulated tape (Figure-6c), testing were done and the results were calculated as per ASTM C1585. For RCPT test, method suggested by American Standards ASTM C 1202[22] was followed on a water-saturated, 50 mm thick, 100 mm diameter specimen subjected to a 60 V applied DC voltage for 6 h as shown in Figure-7. These specimen were fixed between the two reservoir, in which one of the reservoir was filled with a 3.0 % NaCl solution and in another reservoir a 0.3 M NaOH solution was filled. During the test, the total charges passed were determined. Also, surface water absorption test was carried out on 100 mm cube specimens as recommended in BS 1881-Part 122 [23]. The cube specimens were pre-conditioned for one week till constant mass was achieved in a similar way to that of sorptivity. The specimens were then immersed in water and mass gained after 30 min, 1 h, 24 h and 48 hwere noted. The ratio of the gain in weight to the saturated weight expressed in percentage is the water absorption rate. Absorption of the specimen in water gives an indication of the open pore volume of the hardened concrete [24]. These tests were conducted on the specimens at ages of 7, 28, 56 and 90 days.

(a)

Figure-6. (a) Volume of permeable voids specimen kept in oven.

(b)

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(c)

Figure-6. (b) Samples in oven; (c) sealed on the side faces of specimen used for sorptivity.

Figure-7. RCPT in progress.

4. RESULTS AND DISCUSSIONS

Fresh concrete properties of the developed SCC mixes are presented in Table4. All the mixes selected satisfied filling, passing and segregation resistance requirements [16].

Table-4. Summary of fresh concrete test results.

Mix type	**Slump flow** (mm)	T_{500} (sec)	**V-funnel** (sec)	PA	**SR** (%)	**Wet density** (kg/m^3)
SCCC	700	6.0	9.2	0.90	5.52	2445
SCCSC1	730	4.0	8.1	0.95	3.38	2075
SCCSC2	750	4.2	8.3	0.88	3.54	2072

4.1 Compressive strength

Basic mechanical properties of the developed SCC mixes are given in Table-5. It was observed that there were steady gains in compressive strength with ages. While 7.55% and 11.44% strength gain were recorded between 28 and 56 days for SCCSC1 and SCCSC2 respectively, 10.09% and 13.84% strength gain were recorded between 56 and 90 days accordingly for SCCSC1 and SCCSC2. For the control mix (SCCC), while 7.47% strength gain occurred between 28 and 56 days, 24.28 % strength gain was observed between 56 and 90 days.

Elastic modulus, splitting tensile and flexural strengths reported in Table-5 were at 28 days. For the developed mixes, the flexural strengths are 4.50 N/mm^2 (21.22% of compressive strength) and 4.00 N/mm^2 (19.90% of compressive strength) respectively for SCCSC1 and SCCSC2 mixes, while that of the control mix is 4.22 N/mm^2 (15.90% of compressive strength). For the splitting tensile strength, the values are 2.89 N/mm^2 (10.90% of compressive strength), 2.56 N/mm^2 (12.10% of compressive strength) and 2.52 N/mm^2 (12.53 % of compressive strength) respectively for SCCC, SCCSC1 and SCCSC2 mixes. These values complies with recommended provisions [25 and 26] and compares favourably with results from other researchers with similar LWA such as oil palm shell (OPS) [27 and28], recycled plastic [29], pumice and tuff [30].

The static modulus of elasticity are 8490N/mm^2 (40.05% of compressive strength) and 7480N/mm^2 (37.21% of compressive strength) for SCCSC1 and SCCSC2 mixes respectively. Though, this values are extremely low in comparison to the control mix (29700 N/mm^2), however, these results are in agreement with similar research outputs, while Jaya and Sekar [9] got 8000N/mm^2 for CSC, Mo *et al* [28] got 8900N/mm^2 for OPS concrete of similar grade at 28 days.

Table-5. Mechanical properties of SCC mixes.

Mix ID	**Compressive strength f_{ck}** (N/mm^2)				**Splitting tensile strength, f_t** (N/mm^2)	**Flexural strength, f_b** (N/mm^2)	**Elastic modulus** (N/mm^2)	**Dry density** (kg/m^3)
	7 days	**28 days**	**56 days**	**90 sdays**				
SCCC	18.30	26.52	28.50	35.42	2.89	4.22	29700	2412
SCCSC1	15.90	21.20	22.80	25.10	2.56	4.50	8490	2000
SCCSC2	14.47	20.10	22.40	25.50	2.52	4.00	7480	1995

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4.2 Water transport properties

4.2.1Water absorption

Result of water absorption tests at the age of 7, 28, 56 and 90 days curing are as shown in Figure-8. At 28 days, the water absorption rates after 48 h are 8.8 % and 9.07 % for SCCSC1 and SCCSC2 respectively, while that of SCCC is just 2.11 %. At 56 days, the water absorption rates after 48 h are 8.2 % and 8.5 % for SCCSC1 and SCCSC2 respectively, while that of SCCC is just 1.1%. Similarly, At 90 days, the water absorption rates after 48 h are 7.7 % and 7.5 % for SCCSC1 and SCCSC2 respectively, while that of SCCC is just 0.81 %. Shafigh et al has reported that there is no distinctive water absorption reduction in fly ash blended concrete at early age [27]. Though, lightweight aggregate concrete tends to have higher water absorption rate generally [8], however Neville [24] reported that a concrete with not more than 10% water absorption rate at 48 hours could be regarded as a good concrete. Teo *et al* [30] also reported water absorption of OPS concrete had 10.6 % at 28 days.

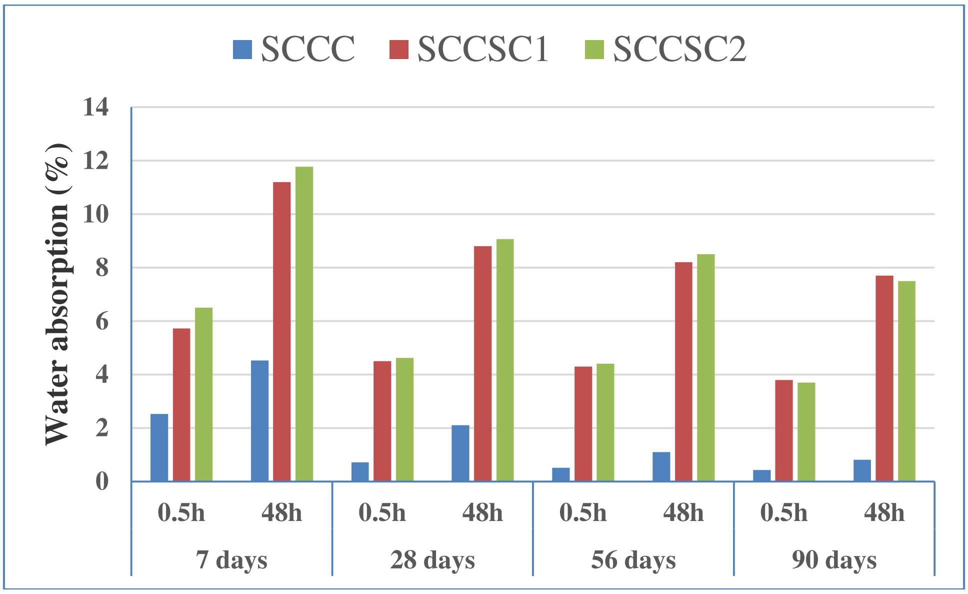

Figure-8. Water absorption rate.

4.2.2Sorptivity

Figure-9 disseminates the results of sorptivity test at an age of 7, 28, 56 and 90 days. Sorptivity test measures water penetration rate by capillary suction into concrete pores. From the results, it could be observed that sorptivity values ranges from 0.155- 0.0.024 mm/min$^{0.5}$ and 0.172 – 0.022 mm/min$^{0.5}$ for SCCSC1 and SCCSC2 respectively, while it has the values of 0.092 - 0.015 mm/min$^{0.5}$ for SCCC. It is important to notice a sharp drop in the observed values from 56 days upward, the pozzolanic reaction of fly ash at later age may be the likely reason for this. These values compares favourably with result of previously published researches on coconut shell aggregate concrete [8].

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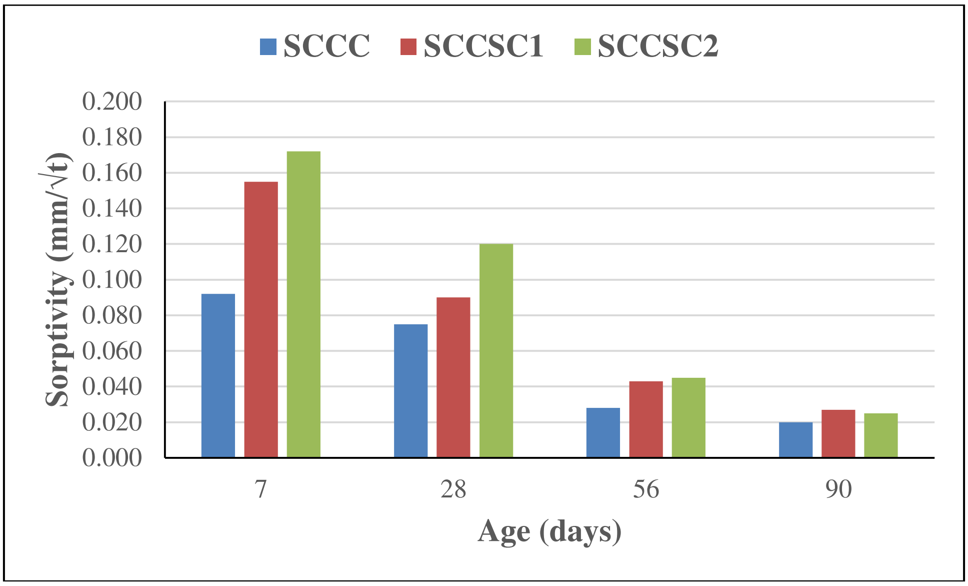

Figure-9. Sorptivity test result.

4.2.3 Volume of permeable voids (VPVs)

VPVs is a method of determining percent voids in a hardened concrete and based on Figure-10, it was observed that total void space in all the mixes decrease as concrete advances in age. Voids volume ranges from 23.45% - 15.30% (34.75% reduction) and 25.63% - 15.11% (41.05% reduction) for SCCSC1 and SCCSC2 mixes respectively (up to 90 days). For SCCC, voids volume ranges from 12.05% - 5.78% (52.03% reduction) up to 90 days.

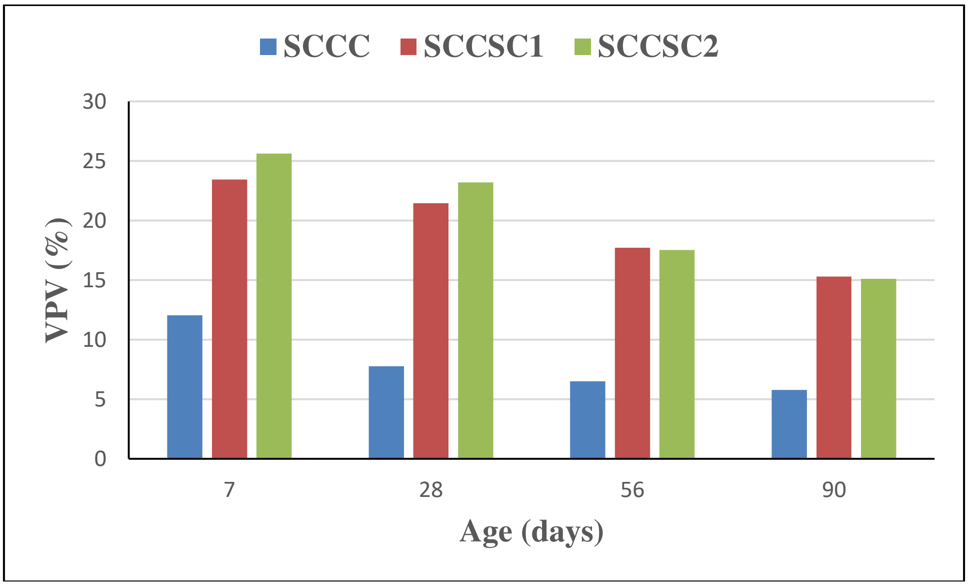

Figure-10. Volume of permeable voids test result.

4.3 Chloride ions diffusivity properties

Ingression of chloride ions from the environment into the concrete leads to corrosion of steel in concrete structures. One common means of evaluating the resistance of concrete to chloride ions ingress is to measure electrical charges passing through concrete specimens in coulombs following the procedures in ASTM C1202. From the result in Figure-11, it was observed that RCPT values ranges from 4088 - 1267 coulombs and 4250 - 1250 coulombs for SCCSC1 and SCCSC2 mixes respectively (up to 90 days). But for the control mix, it ranges from 905 - 422 coulombs. Hence, according to ASTM C1202 [22] classifications, moderate chloride ions penetration is expected in SCCSC1 and SCCSC2 before 90 days and low penetrability afterwards. But the chloride ions penetration for SCCC is very low throughout.

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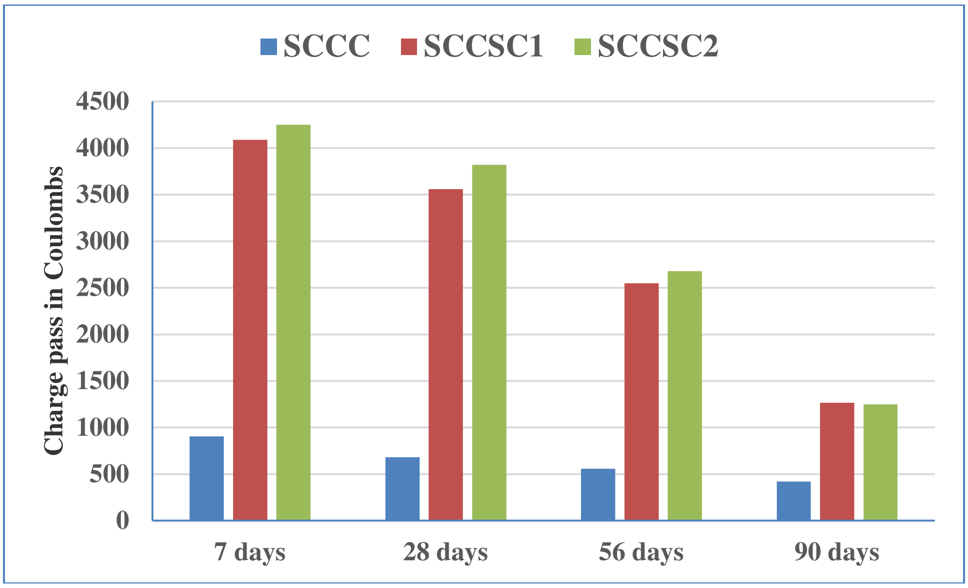

Figure-11. RCPT test result.

Despite CS being fibrous in nature, low water permeability of the concrete samples must have been due to refine pore structures resulting from combined effect of internal curing through the stored water in CS aggregates and pozzolanic reaction of the added fly ash. These ensure hydration process is continuous and formation of large quantity of C-S-H gels with subsequent reaction of fly ash with $Ca(OH)_2$ resulting in very dense microstructure especially at the aggregate-paste interface. Figure-12 illustrated the sections across the sample specimen of SCCC, SCCSC1 and SCCSC2 mixes at 28 days.

Figure-12. Sections across the specimen of all three mixes.

5. CONCLUSIONS

Self-compacting concrete using coconut shell as aggregate is developed with satisfactory test results for self compactibility. Slump flow, T_{500}, V-funnel, L-box and wet sieve segregation resistance tests were conducted and confirmed that the developed mixes are self-compacting concrete. In general, mechanical properties tests gave satisfactory results, durability properties such as water absorption, sorptivity, volume of permeable voids and rapid chloride penetrability compare reasonably well with the other lightweight concretes. Therefore, coconut shell can be taken as an alternate aggregate in the recent development of concrete technology. This will create double advantages of construction cost reduction and cleaner environment.

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Conflict of interest

The authors hereby declare that there is no conflict of interest.

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