

The Performance of Rice Husk Ash and Calcined Clay in Ternary Self-Compacting Concrete

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Abstract

The use of Self-Compacting Concrete (SCC) has become indispensable in the construction of heavily reinforced concrete structures. The cost of Portland limestone cement (PLC), which is the traditional hydraulic cement, is very high. It is more pronounced in developing countries like Nigeria. Rice Husk Ash (RHA) is a waste material that constitutes an environmental hazard in many developing nations. This research is aimed at producing blended self-compacting concrete using RHA and Calcined clay (CC) with Cement Kiln Dust (CKD) as a filler material. Laboratory experimental procedures were used in the work. The physical and oxide composition tests for some of the materials were carried out. 15 percent of PLC was replaced with RHA and CC separately. In each case, ternary blends of RHA-PLC-CKD and CC-PLC-CKD were used to produce a grade 30 SCC. The SCC was tested for fresh and hardened properties. Standard Electronic Microscopy (SEM) tests of the concrete were carried out. The mean specific gravity of the RHA and CC are found to be 2.07 and 2.57 respectively. RHA blended SCC shows greater durability values than the CC blended Self-Compacting Concrete. The average compressive strength of RHA and CC Self-Compacting Concretes at 28-day are 35.0 and 30.4 N/mm² respectively. RHA blended SCC shows a higher compressive strength of 17 percent at 56-day. The average tensile strengths at 28-day are 3.8 and 3.5 N/mm² for RHA and CC blended Self-Compacting Concrete respectively. The Sorptivity indices for RHA and CC Self-Compacting Concretes at 28-day are 0.030 and 0.034 cm/S^{1/2} respectively. RHA blended Self-Compacting Concrete performs better at both the fresh and hardened states as compared to CC blended Self-Compacting Concrete. However, both materials met the design strength at the age of 28 days. The use of RHA at 15% replacement of PLC in SCC production is therefore recommended, especially when durability is considered critical.

Keywords: Self-Compacting Concrete, Rice-Husk-Ash, Calcined Clay, Compressive Strength, and Pozzolanic Reaction.

Introduction

The achievement of the Sustainable Development Goal (SDG) of providing adequate housing and critical infrastructure requires the use of local and readily available construction materials that are economical and environmentally friendly. Concrete is one of the most used construction materials in the world. Therefore, its production should impact positively the economy and environment (Taku and Amartey, 2016). To ensure that concrete satisfies its intended use during its lifetime as well as the evolving needs of the construction industry, various improved forms of this product have been developed,

especially in the last century when architects and construction engineers have ventured into very complex designs and construction. One such revolutionary concrete is Self-Compacting Concrete (SCC). Al-Rubaye (2016) defines SCC as concrete that can fill a whole mold with minimum defects and can compact under its self-weight alone without any external vibrations. The concrete so produced is sufficiently cohesive, flows without segregation or bleeding, and has very reliable quality. SCC was first developed in Japan in the 1980s. The evolution of SCC has eased the construction of structures with extremely complex reinforcement arrangements. This is because the difficulties associated with vibrations of normal concrete in those types of construction are eliminated. Thus, construction time, energy, and financial resources are greatly reduced.

The production of self-compacting concrete requires a large quantity of cement compared to normally vibrated concrete (NVC). Cement is very costly in developing nations and it is not environmentally friendly (Barbhuiya, et al, 2014). These problems are reduced by the development of sustainable SCC that requires the use of large amounts of Secondary Cementitious Materials (SCM) and Fillers. They reduce the segregation of concrete and increase its flowability (Taku, et al, 2021c).

Recent research efforts were aimed at incorporating locally available pozzolanic and filler materials into SCC to improve its quality at a reduced cost (Ouchi, et al, 2000; Zhu and Bartos, 2003). Two materials that are readily available and suitable for use as SCM are Calcined Clay (CC) and Rice-Husk Ash (RHA). The materials have been used individually in NVC and also SCC with positive results (Mahure and Vanjare, 2013; El-Mohsen, et al, 2014; Alkhatib, et al, 2020). Cement-Kiln Dust (CKD) is being used as filler material in SCC. The two ternary self-compacting concretes being investigated are PLC-CC-CKD and PLC-RHA-CKD.

Compressive strength (σ_c) is defined in equation 1, expressed in N/mm² (ASTMC 39, 2014).

$$\sigma_c = \frac{\text{Load at Failure}}{\text{cross-sectional Area}} \quad (1)$$

The tensile strength of concrete using a split cylinder is given in equation 2, expressed in N/mm² (ASTMC 496, 2017).

$$\sigma_t = \frac{2P}{\pi LD} \quad (2)$$

P is the crushing load, and L and D are the length and diameter of the concrete cylinder.

The durability property of the SCC is evaluated by determining its permeation using sorptivity and water absorption. Sorptivity is the susceptibility of the unsaturated concrete to the penetration of water through capillarity action. It is determined by measuring the mass of water absorbed by the specimen when only one surface is exposed to water (Barkat, et al, 2019; Karatas, et al, 2020). Water absorption (WA) is the quantity of water absorbed by a specimen after it is submerged or partially submerged in water for 24 hours.

This research is aimed at comparatively evaluating the properties of blended Calcined clay and Rice-Husk Ash Ternary Self-Compacting Concrete, using cement-kiln dust as filler material. The objectives are to:

- i. Determine some of the physical, chemical, mineralogical, and morphological properties of the materials to be used in this research.
- ii. Investigate the flowability, passing ability, and segregation-resistant properties of the ternary concrete.
- iii. Test the Strength development of the ternary self-compacting concrete at 28 and 56 days of curing.
- iv. Evaluate the micro-structural properties of the hardened ternary Self-compacting concrete.
- v. Evaluate the durability performance of the ternary Self-compacting concrete.

Self-compacting concrete reduces the cost, energy, and time required in the construction of structures. The use of rice-husk ash and calcined clay to produce SCC will boost its production. RHA and CC are pozzolanic materials. They increase the strength and density of concrete as it hardens. These make their concrete to be durable. Their availability in large quantities locally is an added advantage.

Materials and Methods

The main materials used in the research work are:

- i. Fine and coarse aggregates; the fine aggregate used is River sand while the coarse aggregate is crushed granite of a maximum size of 10mm. All the aggregates were obtained in Makurdi, Benue State, Nigeria. Specific gravity, moisture content, and grading tests were carried out as outlined in BS 812 (2002).
- ii. Cement; cementitious materials used include Portland-Limestone Cement (PLC), Rice-Husk Ash (RHA), and Calcined Clay (CC) Pozzolanas. A grade 42.5N PLC was obtained in Makurdi, Nigeria and it was used as supplied. Calcined clay was obtained from the Nigerian Building and Road Research Institute (NBRRI) pozzolana plant in Bokkos, Plateau state. Rice-Husk Ash was produced locally by calcination of the husks in the oven at about 700°C and then sieved through a 45µm sieve. Both RHA and CC were used as secondary cementitious materials.

Portland-Limestone Cement, Rice-Husk Ash, Calcined Clay, PLC-CC (content: 15% of PLC) mix, and PLC-RHA (content: 15% of PLC) mix were tested for setting times, specific gravity, and fineness as described in BS 4550, 3-7(1978). The chemical and morphological properties of CC and RHA were determined using Standard Electronic Microscopy (SEM), and X-Ray Diffraction (XRF) analyses.

Mix Design

The quantities of the components of the Self-Compacting Concrete used were determined using the absolute volume mix design for grade 30 concrete. The constituents were adjusted based on the provisions of EFNARC (2005). The mix was tested for flowability, passing ability, and segregation resistance as spelled out in the Code.

Strength

The determination of the compressive strength of the SCC was carried out using 100mm cubes of the concretes in line with the procedure outlined in BS EN 12390–3 (2009). The tensile strength was determined using 100 by 300mm cylinders as outlined in BS EN 12390–6 (2009). The compressive strength was determined at 7, 14, 28, and 56 days of curing. The average tensile strength was determined on the 28-day.

Durability

The durability characteristics of the SCC were evaluated by using sorptivity and water absorption tests as specified in ASTM C 1585 (2013) and ASTM C642 (2006) Methods respectively. The sorptivity test was carried out at 28 and 56 days of curing for each mix. 12, 50 x 100mm concrete discs were produced and used to determine the sorptivity. The water absorption test was carried out on 50mm cubes of concrete as described in BS 1881-122 (2011) Methods. The test was carried out at 7, 14, 28, and 56 days of curing.

Standard Electronic Microscopy (SEM) Test

The concrete samples were subjected to Standard Electronic Microscopy (SEM) analysis. The range of scale used in SEM analysis is 5µm with a resolution of x5000. The cube samples were crushed and the hydrated concrete was collected from the innermost core of the concrete cube sample. The collected samples were sieved through a 300µm sieve. The sample preparation was done by cone and quartering methods. The sample was poured from a cone tool on a flat surface. The top of the conical-shaped sample was flattened and then divided into quarters. Two opposite quarters were discarded and the other two mixed. The process is repeated until a suitable sample size for the REM Machine was collected.

Results and Discussion

The test results of the properties of the materials used in the research are shown in Table 1. The specific gravity of Portland-Limestone Cement, Rice-Husk Ash, and the aggregates are similar to those found in the literature (Obam and Tyagher, 2011). Accurate determination of specific gravity could lead to adequate proportioning of concrete ingredients. Rice-Husk Ash has very high initial and final setting times, which is typical of pozzolanic materials. These materials delay the early setting and hardening of concrete. The oxide composition of the materials is shown in Table 2. RHA contains about 51% more of SiO² (Silica) than CC, indicating its greater potential for pozzolanic activity. Figure 1 shows the grading curve for the River sand. It belongs to grading curve C (Neville, 2011). It is suitable for high-grade concrete production.

The Flowability, Slump Flow, and V-funnel Test Results are shown in Table 3. The results of the flowability test indicate that the mix in both cases belongs to viscosity class VS₁/ VF₁ based on the values of t_{500} and V_{funnel} time respectively. These indicate that the SCC class is SF₂. In both cases, the concretes show flowability characteristics similar to what is specified in EFNARC (2005). Satisfactory flowability indicates good quality of SCC. RHA blended Self-

compacting concrete shows better flowability values than the calcined clay blended Self-compacting concrete. This might be due to the swelling nature of clay when in contact with water which may have reduced its flowability. The result agrees with Manu and Dinakar (2015) and Zayed (2018). According to the European guidelines for SCC (EFNARC, 2005), SCC class SF2 is suitable for most normal applications.

The filling and Passing Ability of CC and RHA blended self-compacting concrete test results are shown in Table 4. According to EFNARC (2005), for proper filling ability, $0.8 \leq H_2/H_1 \leq 1.0$ condition must be satisfied. It can be seen from the table that the inequality condition is satisfied for both concretes. The results are similar to the ones produced by Ryu, et al, (2019) and Kadhum and Owaid (2020).

Figure 2 shows the results of compressive strength versus age of the concretes. As expected, the compressive strength increases with age for both concretes. At the age of 28 and 56 days, RHA blended concrete gained more strength than the Calcined clay blended concrete by about 13 and 17 percent respectively. This could be due to the pozzolanic reaction between RHA and calcium hydroxide (CH) released during the hydration of PLC. RHA has higher pozzolanic activity than CC (Bumanis, et al. 2016 and Yu, et al, 2021). The maximum tensile strength for CC and RHA blended concretes, at 28-day, are 3.5 and 3.8 N/mm² respectively. Concrete tensile stress is important in some Civil engineering structures like Aeroplane Runway and Shell Roof where concrete is expected to resist tensile load.

The results of Water Absorption and Sorptivity tests on the Concretes are shown in Figures 3 and 4 respectively. It can be observed from Figure 3 that the rate of water absorption is higher for calcined clay blended concrete than for rice-husk ash blended concrete. This could be due to the additional pores created by the swelling of the clay when it absorbs water. Also, RHA blended concrete is denser because of its higher pozzolanic reaction. We observe from Figure 4 that the rate of capillary water absorption with the square root of time (sorptivity) decreases with the age of the concretes. This might be due to the increased hydration and pozzolanic reaction that lead to more dense and hardened concrete. High water absorption of concrete could lead to its early deterioration.

Plates 1 and 2 show the REM analysis results of RHA and CC blended SCC at 56-day curing respectively. It is observed from Plates 1 and 2 that the RHA blended SCC is denser in micro-structure than the CC blended concrete. Dense concrete performs well in structure and is durable. Again, this could be attributed to the higher pozzolanic reaction of RHA than the CC.

All the results of the properties of the concretes show that PLC-RHA-CKD blended ternary SCC are superior to PLC-CC-CKD blended ternary SCC. However, both met the minimum strength requirement for structural concrete.

Conclusion

The research investigated the performance of two types of blended ternary Self-Compacting Concretes (SCC); PLC-RHA-CKD and PLC-CC-CKD. SCC is important in the construction of heavily reinforced concrete structures. Rice-Husk ASH and Calcined Clay are available in large quantities in many parts of Nigeria. The specific gravity of RHA and CC are found to be 2.07 and 2.57 respectively. RHA contains about 51% more of SiO₂ (silica) than CC. This indicates that Rice-Husk ASH could be more pozzolanic than Calcined Clay. The two concretes belong to viscosity class SF2. This implies that the concretes are flowable; a good quality of Self-Compacting Concrete. The concretes also show satisfactory Passing and Filling Ability requirements of SCC. The average compressive strength of RHA blended self-compacting concrete is about 13 and 17 percent more than that of CC blended self-compacting concrete at 28 and 56-day respectively. RHA blended concrete is shown to be more impermeable. This implies that it could be more durable than CC blended concrete. REM analysis shows that RHA blended concrete has a more dense micro-structure than CC blended concrete. Dense concrete often exhibits high strength and durability.

Recommendations

- When the durability of a structure becomes a critical factor, PLC-RHA-CKD blended ternary SCC concrete is recommended.
- Other materials with high pozzolanic activity should be investigated in the production of SCC. Pozzolanas enhance the strength and durability of concrete.

Table 1: Test Results of Some of the Properties of the Materials

Material	Initial setting Time (Min)	Final setting Time (Min)	Sound -ness (mm)	Specific gravity	Consistenc y	Fine -ness (%)	AC V (%)	AIV (%)	Moistu -re conten t (%)
PLC	51	126	2	3.50	25	4.86	-	-	-
Calcined Clay	-	-	-	2.57	-	-	-	-	-
Cement Kiln Dust	-	-	-	2.71	-	-	-	-	-
Rice Husk Ash	276	4560	-	2.07	-	-	-	-	-
PLC+15%CC	155	215	2	-	31	-	-	-	-
PLC+15%RHA	149	205	2	-	29	-	-	-	-
Fine Aggregate	-	-	-	2.65	-	-	-	-	14.6
Coarse Aggregate.	-	-	-	2.69	-	-	21.0	24.5	-

Table 2: The Test Results of Oxide Composition of the Materials (%)

Oxide	Al ₂ O ₃	SiO ₂	CaO	Fe ₂ O ₃	K ₂ O	MnO	SO ₃	TiO	BaO	V ₂ O ₅	Cr ₂ O ₃	LOI
CC	46.9	35.6	0.02	15.38	0.18	1.8	0.03	0.2	0.11	0.1	0.03	11.0
PLC	1.8	8.57	79.12	4.28	0.24	0.48	1.6	2.51	0.12	-	-	1.71
CKD	1.00	4.36	89.56	1.60	0.34	1.61	0.05	0.08	-	-	-	37.7
RHA	3.48	72.5	1.78	9.82	0.21	6.02	4.63	0.23	0.16	0.03	-	-

Table 3: The Test Results of Flowability, Slump Flow and V-funnel

Pozzolana	t ₅₀₀ (s)	Viscosity class	t _{flow} (s)	d ₁₋ (mm)	d ₂₋ (mm)	Slump- flow (mm)	SCC class	V _{funnel--} time (s)
CC	0.45	VS1/VF1	4.0	715	715	715	SF2	5.30
RHA	0.36	VS1/VF1	4.2	730	730	730	SF2	5.94

Table 4: The Test Results of Filling and Passing Ability of Calcined Clay and Rice-Husk Ash blended SCC

L-Box Test results							J-Ring Tests results		
Pozzolana	Filler*	H ₁	H ₂	H ₂ /H ₁	T ₂₀₀ (s)	T ₄₀₀ (s)	d _{Jx} mm	d _{Jy} mm	SF _J
CC	CKD	7.9	7.5	0.95	0.46	1.20	705	705	705
RHA	CKD	8.4	8.3	0.99	0.38	1.07	715	715	715



Figure 1: The Grading curve of the River Sand

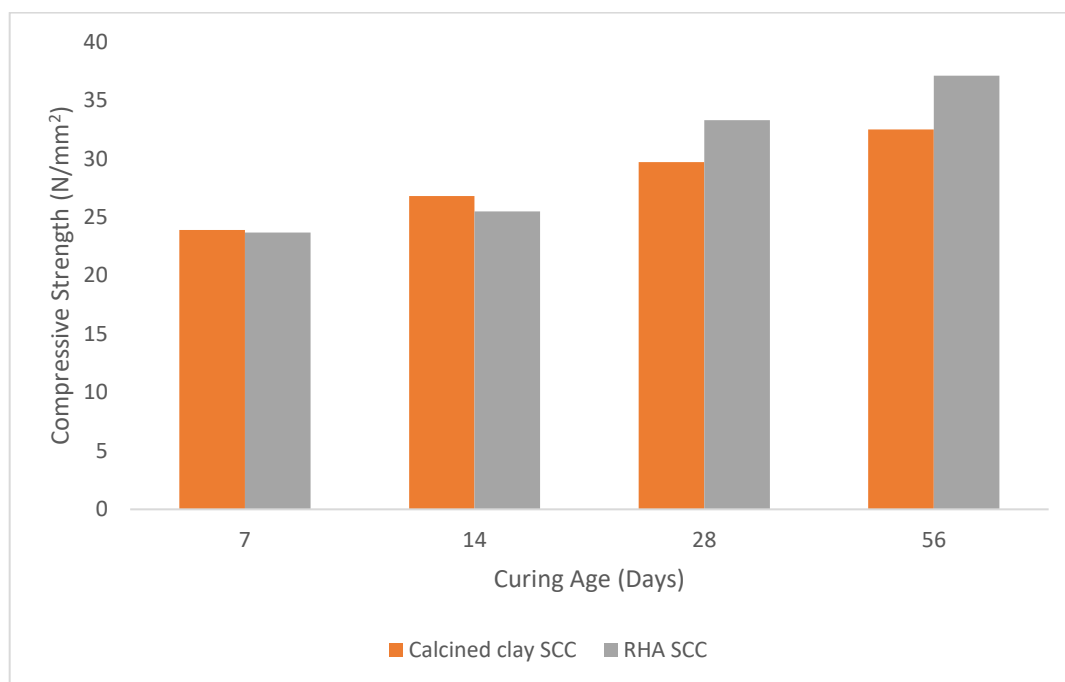


Figure 2: The Variation of Compressive Strength versus Age of the Concretes

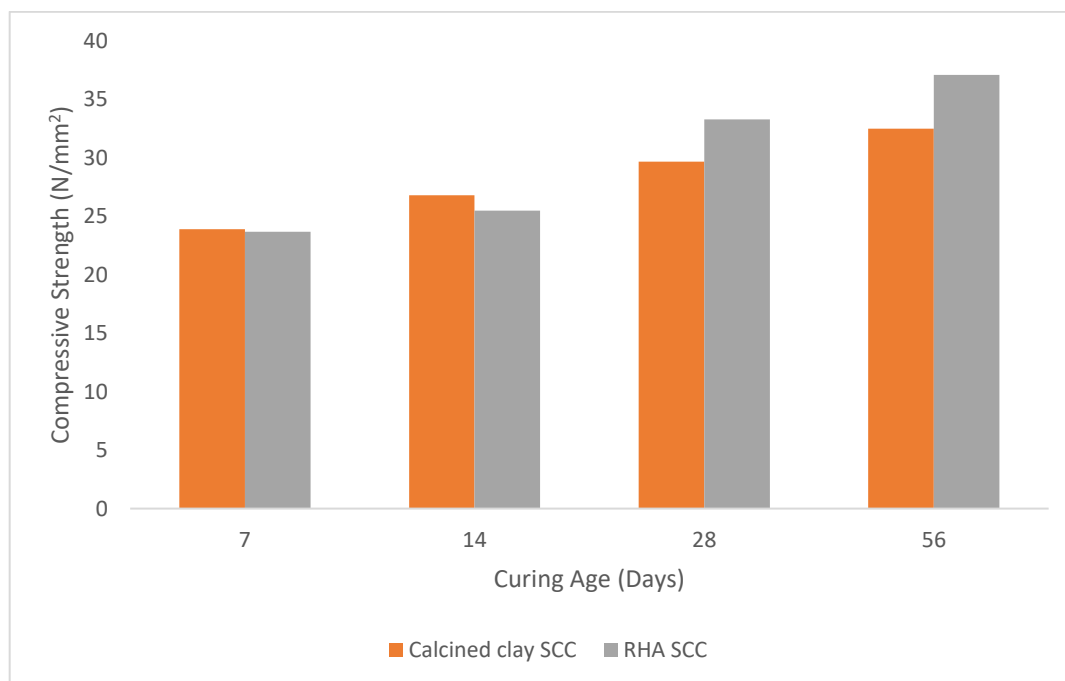


Figure 3: The Variation of Compressive Strength versus Age of the Concretes

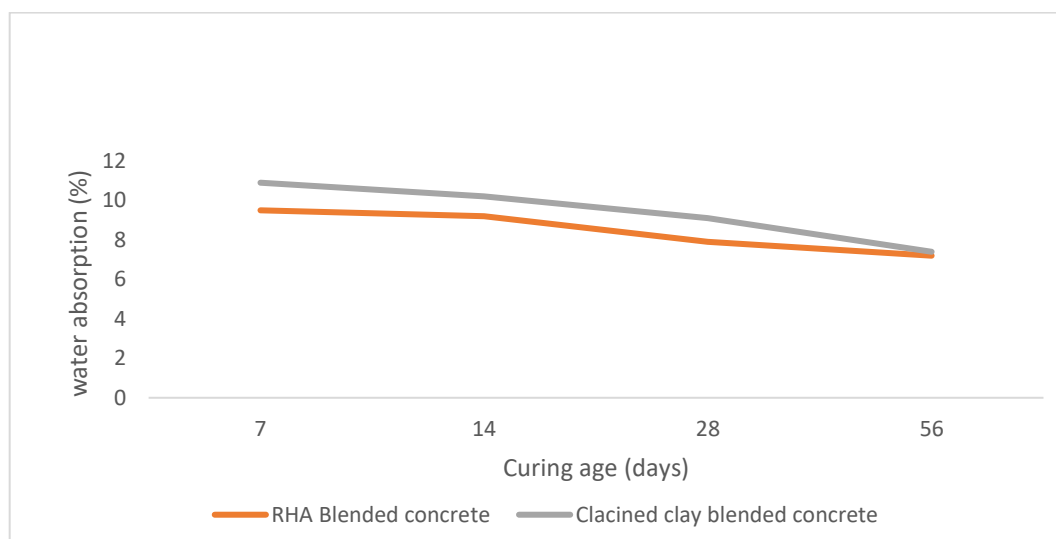


Figure 4: The Water Absorption versus Age of the Concretes

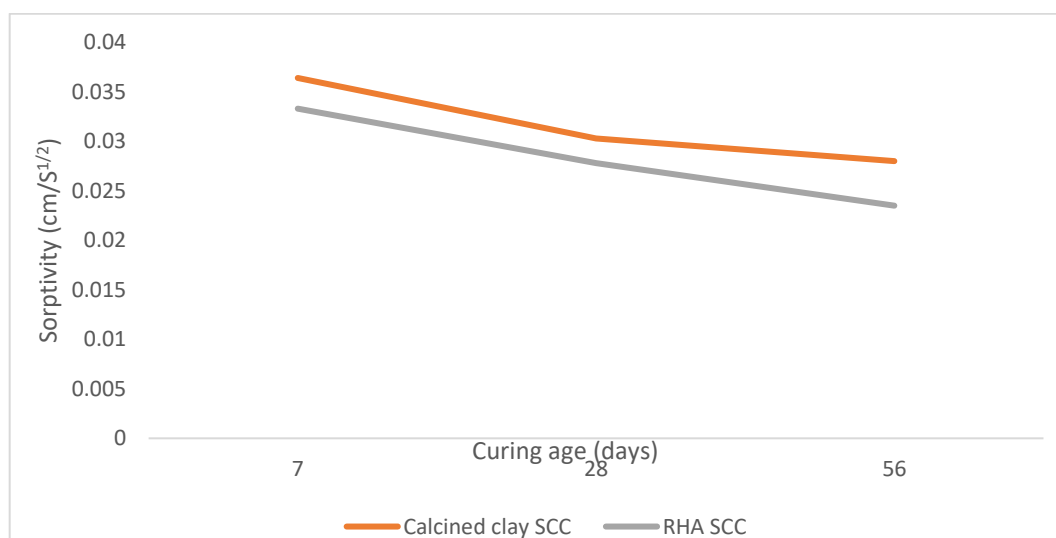


Figure 5: Sorptivity of the Concretes versus Age

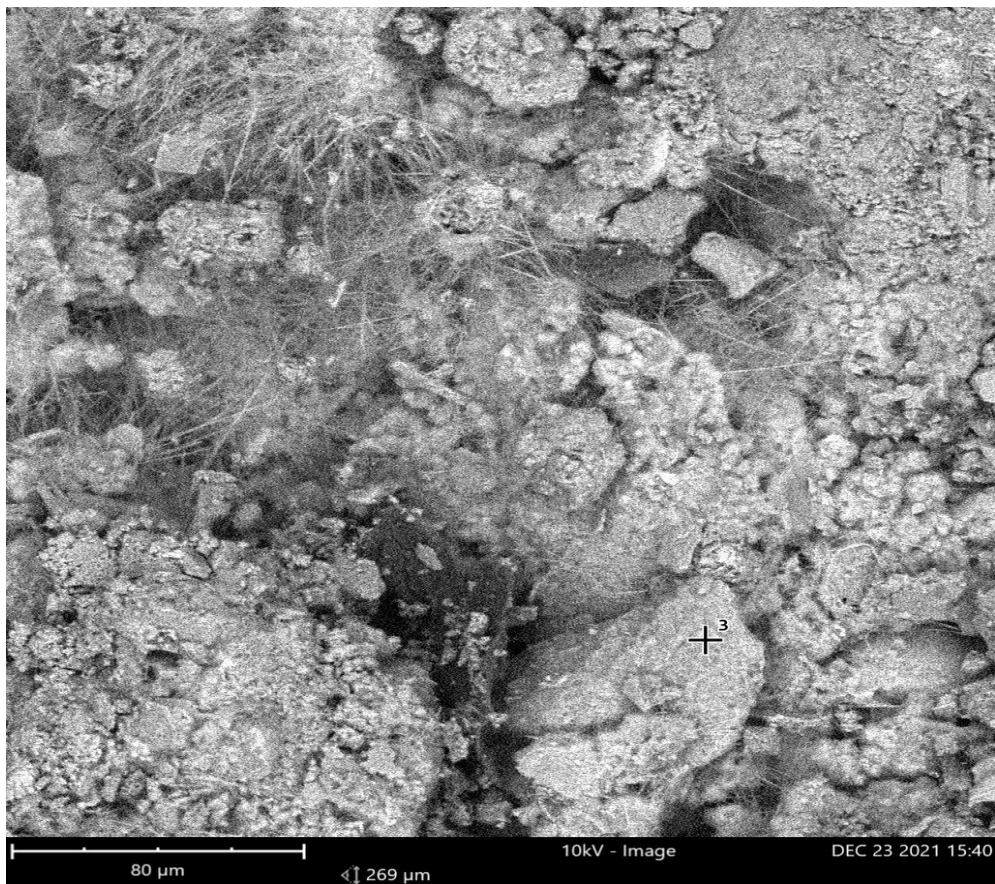


Plate 1: The SEM analysis Result of RHA blended SCC at 56-day

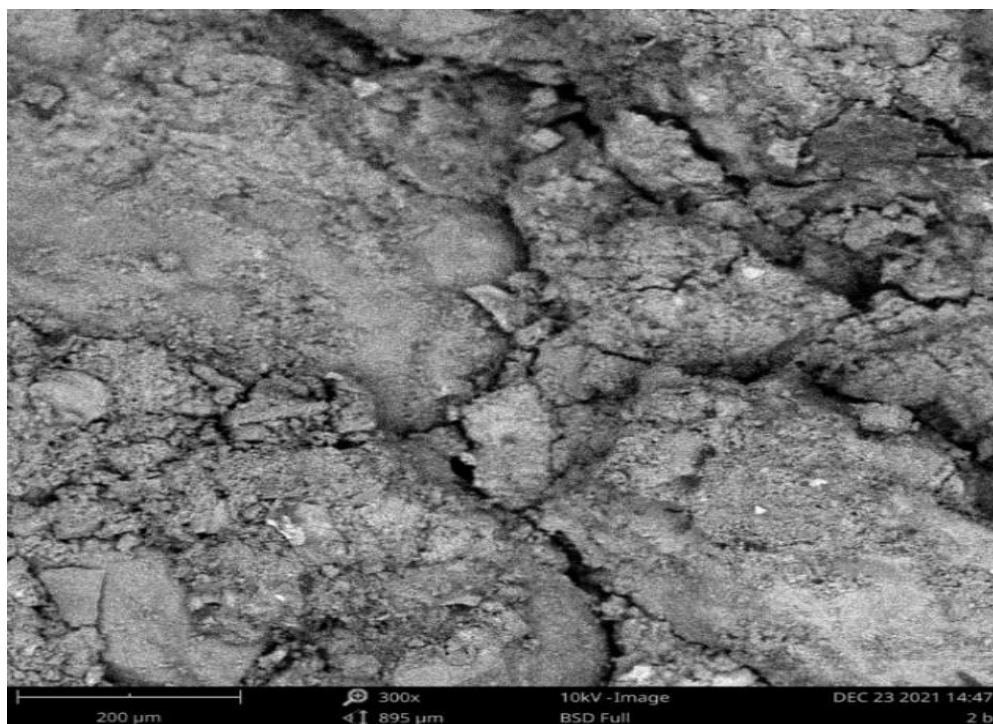


Plate 2: The SEM analysis Result of calcined clay SCC at 56-day

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