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Effectiveness of Rice Husk and Sugarcane Bagasse Ashes Blended Cement in Improving Properties of Concrete

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Abstract

This paper emphasized the use of rice husk ash (RHA) and sugarcane bagasse ash (SBA) in improving concrete properties, and also their combined effects on workability, compressive strength, flexural strength, permeability and water absorption capacity. Thus, in this study, the water-to-cement ratio was kept constant (0.45), the binder materials content for conventional mix was kept constant at (350 kg/m^3) and the partial replacement of cement with RHASBA used was 5%, 10%, 15%, 20%, 25%, and 30% by weight of cement. The maximum compressive strength was noted at a 5% replacement level of cement with RHASBA. The Results showed that the optimum replacement of cement with RHASBA in concrete was 5%, which was found to increase the compressive strength by 15%, flexural strength by 3.4%, lowered permeability by 50%, lowered sorptivity by 11.34% as compared with control concrete at 90 days of curing time. The micro-structural test results further established that RHA and SBA have a high content of SiO_2 which enables them to be more reactive in concrete and also revealed that the presence of RHASBA depletes $Ca(OH)_2$ crystals, converting it into CaH_2O_4Si (C-S-H gel) leading to the strengthening of bond within the concrete matrix.

Keywords

Concrete, Rice Husk Ash, Sugarcane Bagasse Ash, Compressive Strength, Permeability, Sorptivity

1. Introduction

In recent decades, the built and construction environments have been persistently faced with numerous issues relating to sustainability of natural materials.

Also, due to the alarming rate of exploration of natural resources, caused by changing human lifestyle and increasing urbanization, there has been an increase in both the demand and cost of natural construction materials. It has become almost impossible for poor communities to develop affordable housing facilities. However, the advances in material research, in recent years, have opened the pathway for the use of alternative materials to be used in place of the conventional ones in the construction industries. The materials represent mostly industrial, construction and agricultural waste like rice husk ash (RHA), sugarcane bagasse ash (SBA), groundnut shell ash, and cassava peel ash etc. Reusing the aforementioned materials will largely contribute to effective waste management through recycling. Deep research on these intended materials brings out their potential and gives the users confidence in their usage. Thus, the current study considers the effectiveness of rice husk ash and sugarcane bagasse ash blended cement (RHASBABC) in the strength, permeability and sorptivity resistance of concrete. Both rice husk and sugarcane bagasse are post-harvesting wastes generated from rice and sugarcane plantations respectively. They are routinely burnt on farmlands as they constitute nuisance. However, studies performed over the years have shown that the materials could be beneficially utilized for mortar/concrete production, owing to their excellent cementitious characteristics. [1] investigated the use of rice husk ash and lime powder (LP) blended cement for concrete production. Their study explored both the strength and microstructural properties of the tested concrete, and it was established that 10% RHA and 10% LP exhibited excellent performance in terms of strength and voids distribution. The study also made it known that an accelerated formation of calcium silicate hydrate (CSH) via rapid pozzolanic action contributed to the performance of the concrete. In a similar study, [2] evaluated the effect of partial replacement of ordinary Portland cement (OPC) with RHA in varying proportions, and it was shown that a 20% level of RHA replacement improved the strength characteristics of the concrete. Also, they reported that durability features in terms of permeability and chloride diffusion capacity of concrete were improved by using RHA. Other studies, [3] [4] [5] also established the suitability of RHA as a pozzolanic material for concrete production. Another agricultural waste that has been persistently investigated is sugarcane bagasse ash as a partial replacement for OPC. [6] Outlined an improvement in concrete made with sugarcane bagasse in properties such as low heat of hydration, permeability resistance due to pore refinement, and drying shrinkage. A related study carried out by [7] also showed that the performance of concrete was enhanced by partially replacing OPC with RHA by up to 15%. Overall, the reports obtained from studies have shown that both RHA and Sugarcane bagasse ash (SBA) exhibited appreciable pozzolanic features that in turn resulted in better strength and micro-scale characteristics in concrete. However, despite the advances in studies involving the use of RHA and sugarcane bagasse as OPC replacement in concrete, there are currently not so much information on a ternary blend of OPC, RHA and SBA as a binder in a concrete mix, based on the claim that workability and strength properties of concrete are affected by the addition of different supplementary cementitious materials [8]. Moreover, properties such as permeability and sorptivity resistance, which are major durability issues in concrete, have not been overly explored in this type of concrete mix. Therefore, this study attempts to determine the effectiveness of rice husk ash and sugarcane bagasse ash blended cement (RHASBABC) in permeability and sorptivity characteristics of concrete.

2. Experiment Aim and Objective

This research investigates the effectiveness of rice husk ash (RHA) and sugarcane bagasse ash (SBA) blended cement for improving mechanical and durability properties of concrete, with the main objective of improving concrete properties by enhancing the pore—distribution and morphological features of concrete and also providing concrete of higher resistance to heat/temperature.

3. Experiment Work Materials

The various raw and processed materials utilized in this research are as follows;

Cement: A grade 42.5 ordinary Portland cement (OPC), conforming to the Nigerian Industrial Standard specifications [9], was used as the main binder for concrete mixing. The chemical composition of the cement used is presented in **Table 1**.

Fine Aggregate: River sand used was sourced from local quarry within Akure, Ondo state, Nigeria and was of the size range of 4.75 mm (No 4) and finer aperture sizes were used as fine aggregate. Well-graded sand with a specific gravity of 2.67 g/cm^3 and fineness modulus of 2.85, which was determined as per [10].

Coarse Aggregate: In this research, crushed rock (granite) of maximum size passing through 20 mm but retained in 16 mm and 10 mm sieves were selected and used for this research. The specific gravity and fineness modulus of coarse aggregate that was used were 2.60 and 7.25 respectively and were in conformity with the British standard recommendations [11].

Ashes: RHA and SBA conform to the requirements of [12], Class F. as given in **Table 1**.

Concrete Mix Design and Proportion

Many trial mixes were done to establish the suitable mix design for the proposed concrete mixtures of grade 20 MPa. The mixtures were prepared using a concurrent partial replacement of OPC with RHASBA in proportions of 5%, 10%, 15%, 20%, 25% and 30% by weight of cement. The content of the binding materials for the control mix was 350 kg/m^3 and constant water-binder ratio of 0.45 was considered. Coarse and fine aggregate content was fixed throughout the experiment. During the mixing of concrete and prior to casting of samples, the workability of the concrete was assessed and after 24 hours, the test specimens were removed and cured for 7, 28 and 90 days by immersion in water tank. Mix Proportions used were listed in **Table 2**.

Table 1. Chemical compositions of ordinary portland cement, rice husk ash and sugarcane Gagasse ash.

Binders	Concentration (%)								
	SiO_2	Al_2O_3	Fe_2O_3	CaO	K_2O	MgO	SO_3	Na_2O_3	LOI
OPC	20.95	5.67	3.95	60.95	2.12	0.98	4.01	0.81	-
RHA	86.45	1.67	1.93	3.23	4.12	0.28	0.01	0.01	5
SBA	85.95	3.69	2.91	2.35	3.78	1.40	0.30	0.02	6

Table 2. Mix proportions for different RHASBABC mixtures.

Cement (Kg/m^3)	RHA (Kg/m^3)	SBA (Kg/m^3)	RHASBA (%)	F. A (Kg/m^3)	C. A (Kg/m^3)	Water (Kg/m^3)	w/b
350	0	0	0	525	1050	157.5	0.45
332.5	8.75	8.75	5	525	1050	157.5	0.45
315	17.5	17.5	10	525	1050	157.5	0.45
297.5	26.25	26.25	15	525	1050	157.5	0.45
280	35	35	20	525	1050	157.5	0.45

4. Testing

4.1. Slump Flow Test

In most cementitious mixes, workability tests such as slump, were carried out on fresh concrete mixes, so as to determine the suitability of the mix for the required construction application. However, in this research, the slump test was performed, and it followed the requirements of [13]. The water-to-cement ratio was selected to be 0.45 and kept constant throughout the experiment. The slump value was taken as the difference between height of the apparatus and concrete height point after shear of the concrete.

4.2. Compressive Strength Test

The strength properties of hardened concrete were determined, which include: compressive strength of 150 mm cubes. Triplicate samples were produced per mix, and average strength was taken as the strength property of the concrete at the stipulated periods. The compressive strength of the concrete samples was determined using a universal compressive testing machine. The optimum replacement of RHASBABC was determined and further experiments were carried out on the optimum RHASBABC concrete and conventional concrete to assess its flexural strength, durability properties and micro-structural features.

4.3. Flexural Strength Test

A flexural test was carried out on control concrete and optimum RHASBABC concrete with dimensions 100 mm × 100 mm × 500 mm. Center point loading test machine was used according to [14]. Specimens were produced in triplicate for each curing age of 7, 28, and 90 days. The flexural strength was computed using Equation (1).

$$\text{Flexural strength of sample} = \frac{PXL}{bd^2} \quad (1)$$

where P is the maximum load applied to the concrete beam,
b is the width of the concrete beam (mm),
d is the failure point depth of concrete beam (mm).

4.4. Durability Assessment

The durability test helps to evaluate the performance of concrete under certain aggressive loading or condition. This research examined two major durability properties of the concrete mixtures, permeability and sorptivity properties. The concrete permeability and sorptivity tests were determined in line with the method discussed by [15] and [16] respectively. A detailed procedure for testing the two methods is described in detail underneath.

4.5. Rapid Chloride Penetration Test (RCPT)

In this study, Rapid Chloride Penetration Test (RCPT) was adopted. The specimens were placed in RCPT migration cells with 3.0% NaCl solution (catholyte) and 0.3 N NaOH solutions (anolyte). A constant potential of 60 ± 0.1 V was applied across the concrete, which will accelerate the penetration of chloride ions from catholyte to anolyte through the concrete specimens. The current readings were recorded at 30 min intervals for 6 H. The total charge passed over the test period was calculated from current readings, to provide a representation of the concrete resistance to chloride ion penetration and result related to ASTM ratings as listed in **Table 3**. The test was done for 7 days, 28 days and 90 days curing period for both control and optimum RHASBABC concrete samples.

4.6. Sorptivity Test

For the sorptivity test, concrete samples were dried in an oven at 50˚C for 3 days and then cooled in a sealed container at 23˚C for 15 days. The surface of the concrete was covered with epoxy resin in order to allow the flow of water in one direction. The end of the samples was sealed with tightly attached plastic sheet and protected in position by an elastic band. The initial mass of the samples was measured, and then samples were kept partly immersed to a depth of 5 mm in water. Sorptivity test was started with the initial mass of the samples at selected times after first contact with water (0, 1, 5, 10, 20, 30, 60, 120, 180, 240, 300, 360, 420 min and 1, 2, 3, 4, 7, 8, 9 days). The samples were removed, and excess water on their surface was blotted off using paper towel and weighed. Again, the samples were replaced again in water for the chosen time period. Finally, the gain in mass (Δm, kg/s$^{1/2}$) at time t (s), the exposed area of the specimen (a, m^2), and the density of water (d, kg/m^3), were used to obtain the rate of water absorption.

Table 3. RCPT ratings in accordance with ASTM C1202-2019.

Chloride Ion Penetrability	High	Moderate	Low	Very low	Negligible
Charged passed C Coulombs	>4000	2000 - 4000	1000 - 2000	100 - 1000	<100

The sorptivity values of concrete were determined using the formula in Equation (2), [6]. Water absorption values "*i*" is plotted against square root of time "*t2*". Slope of the best-fit line is the sorptivity value.

$$i = St^{1/2} \tag{2}$$

where i is the cumulative water absorption per unit area of inflow surface;

S is the sorptivity in $m \cdot s^{-1/2}$ and;

t is the time elapsed in seconds.

4.7. Micro Scale Evaluation

This research evaluates the microstructural properties of the concrete mixtures of ordinary Portland cement and optimum RHASBABC after durability tests, so as to understand the intrinsic features of the concrete that warrant the observed strength and durability characteristics. The tests performed include, examination of concrete morphology using SEM equipment in the secondary electron mode, X-ray diffraction (XRD), thermo gravimetric analysis (TGA) and differential thermal analysis (DTA).

5. Results and Discussion

5.1. Slump Flow Test

From the test results, the slump decreases as the amount of RHASBA increases in the concrete mix within the range of 35 mm to 20 mm as shown in **Figure 1**. The reduction in slump was a result of water absorption capacity of RHASBA in concrete matrix. This is due to the physical properties of RHA and SBA, as they tend to absorb more water in the concrete mixture than OPC concrete.

5.2. Compressive Strength Test

RHASBA was blended with cement at 5% intervals and up to 30% replacement in concrete mix to test for the compression strength. It was observed that there was steady improvement in the compressive strength of all concrete samples with respect to curing age, except for 20% to 30% RHASBABC concrete samples that declined in strength after 28 days. The strength exhibited by OPC concrete at 7 and 28 days was higher when compared with RHASBABC concrete, and this could be traced to higher initial strength development in OPC concrete. [16] reported that concrete mixture with pozzolanic materials exhibited low gain of early age strength until later age that got its strength appreciably increased. At 90 days, the strength of concrete with 5% RHASBABC increased by 15% compared with OPC concrete, which shows the positive effect of pozzolanic element in the concrete matrix. Replacement of cement with RHASBABC above 5% declined in

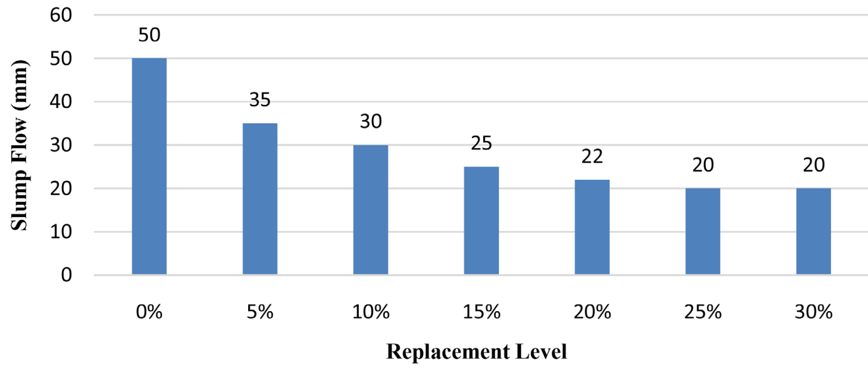


Figure 1. Slump flow test results.

the strength may be a result of influence on the hydration process of the binding agents, because when hydration of cement stops before hydration is complete, strength decreases accordingly as shown in **Figure 2**. The highest compressive strength of concrete at 90 days of curing time was (25.47 N/mm^2) in 5% RHASBABC concrete as compared with control concrete (21.65 N/mm^2). Therefore, 5% RHASBA was noted to be the optimum partial replacement of cement in concrete as obtained in this research for higher strength and high-grade concrete. Also, 10% RHASBABC can be adopted for weak concrete, as gotten by [17].

5.3. Flexural Strength Test

The study on flexural strength is crucial for this study, simply based on the relationship between compressive strength and tensile strength of concrete. The flexural test was used to evaluate the tensile strength of concrete indirectly. The flexural strength at 7 days was 4.97 N/mm^2 in OPC concrete as against 4.54 N/mm^2 in 5% RHASBABC concrete, but in the later days, RHASBABC concrete increased in strength by 3.5% as compared with OPC concrete as shown in **Figure 3**. This is an indication that the presence of pozzolanic reactivity in concrete takes a longer hydration process.

5.4. Rapid Chloride Penetration Test (RCPT)

A rapid chloride penetration test was conducted on OPC concrete and 5% RHASBABC concrete. The total charges (coulomb) passed at 7, 28, 90 days for both samples were presented in **Figure 4**. From the results, it was noted that charges passing through 5% RHASBABC concrete were lowered compared to OPC concrete and the reason was simply because of fine particles and strong bonding between particles reduced these charges. At 90 days, charges passed in 5% RHASBABC concrete fell under "low level" (1125 coulombs) as compared with OPC concrete which was under "moderate" level (2525 coulombs) as mentioned in **Table 3**. The value of charges passed at 7 and 28 days was 3400 coulombs (moderate) and 3000 coulombs (moderate) for OPC concrete while for 5% RHASBABC concrete were 3335 coulombs (moderate) and 2225 coulombs

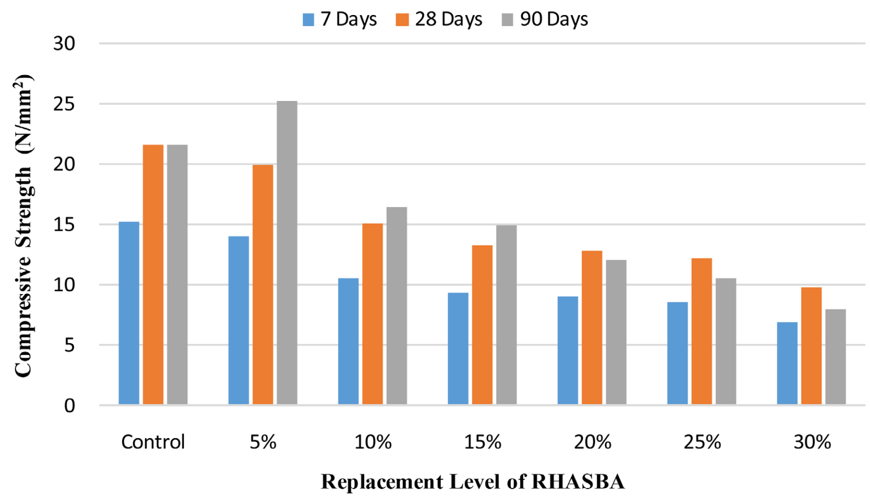


Figure 2. Compressive strength test results.

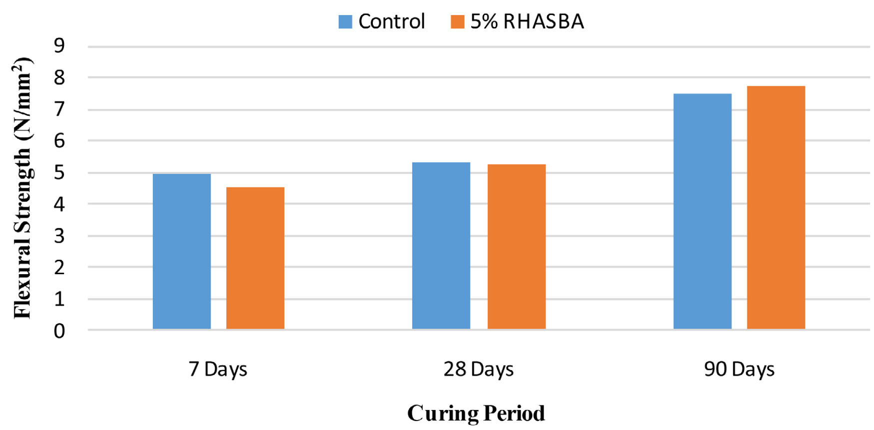


Figure 3. Flexural strength test results.

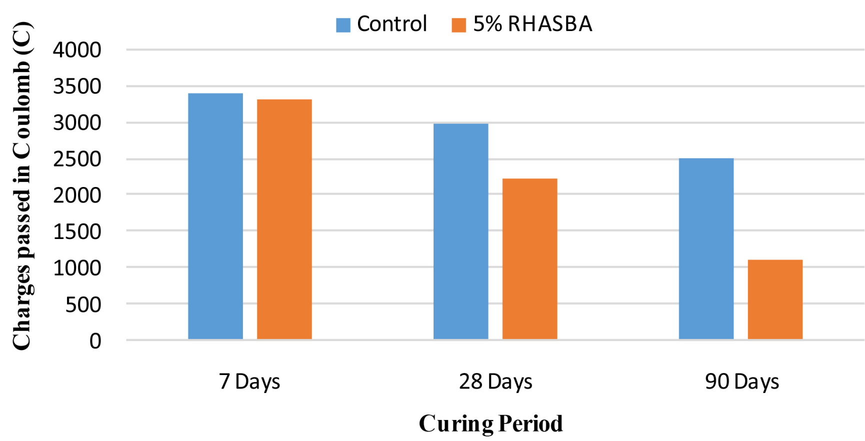


Figure 4. Test results of Rapid Chloride Penetration Test (RCPT).

(low), respectively (Figure 4). The chloride ion penetration was lowered in 5% RHASBABC concrete compared with OPC concrete and this was reported in Figure 5. This implies that the lower the chloride ion penetration, the lower the

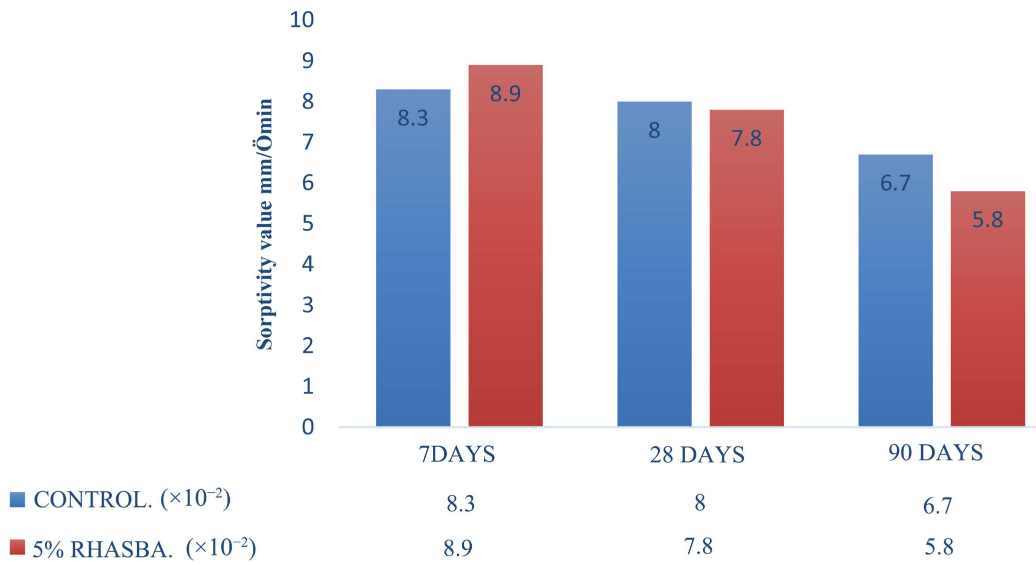
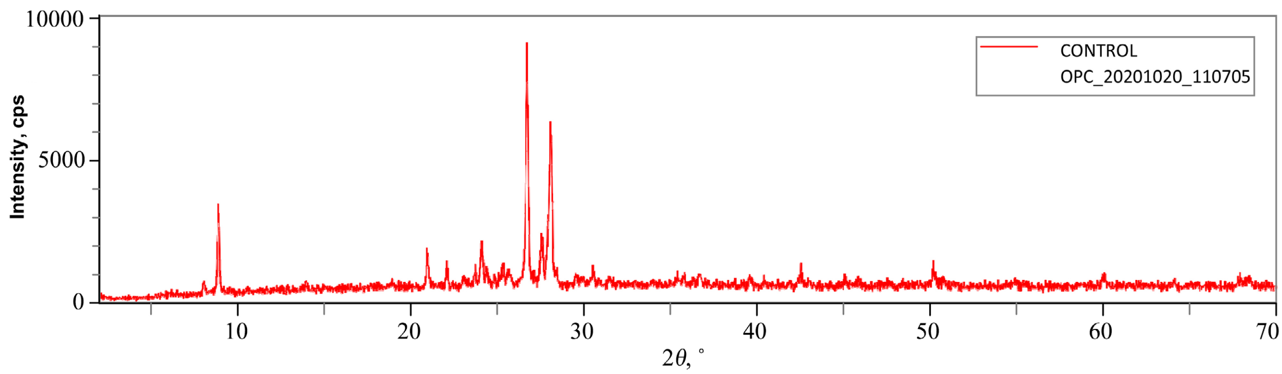


Figure 5. Later age absorption value of concrete made of OPC and 5% RHASBABC.

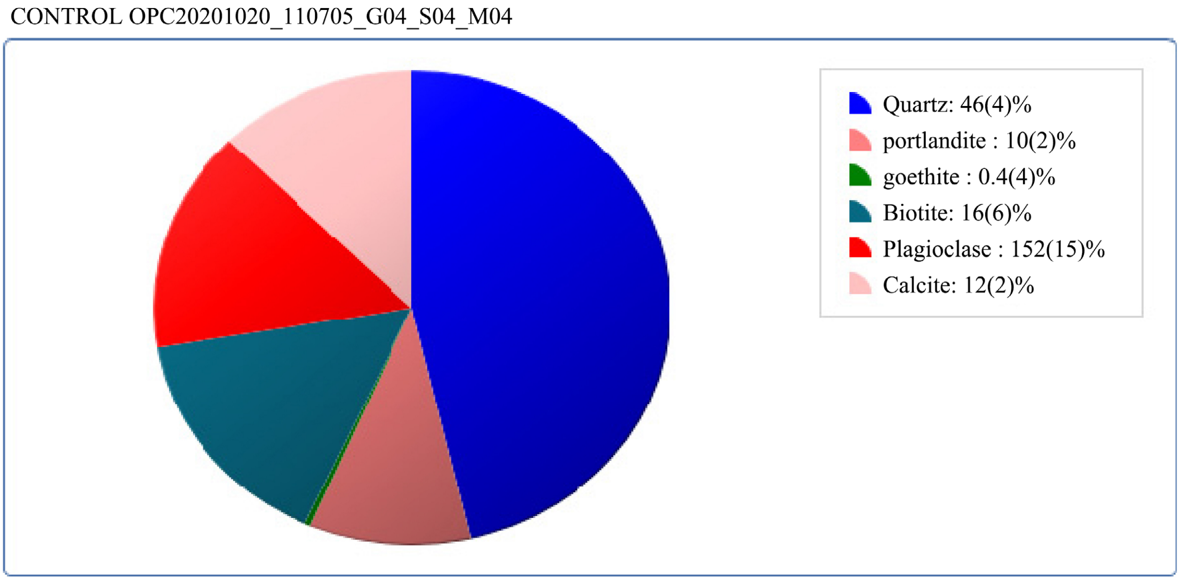
permeability and the more resistant power of the concrete to carbonation. RHASBABC concrete shows better resistance to chloride attack compared to conventional concrete.

5.5. Sorptivity Test

Table 4, reveals the water absorption for both OPC concrete and 5% RHASBABC concrete at 7 days, 28 days, 90 days curing time. Water absorption capacity of concrete sample represents its permeable and porous features. Concrete durability is affected by the increase in concrete permeability. A lower value in this respect denotes concrete penetrability resistance. The test results show that as time increases, the rate of water absorption decreases and this is an indication that concrete penetrability resistance increases with curing time [18]. The rate of water absorption was lowered by 11.34% in 5% RHASBABC concrete as compared with OPC concrete at 90 days curing period. **Figure 5** shows the sorptivity coefficient values for later age absorption time. It was noted that sorptivity gradually decreases in 5% RHASBABC concrete (7.8×10^{-2} mm/min^{½}, 5.8×10^{-2} mm/min^{½}) as compared with OPC concrete (8.0×10^{-2} mm/min^{½}, 6.7×10^{-2} mm/min^{½}) for 28 days and 90 days curing time. It shows the effect of pozzolanic reactivity in RHASBA which has the ability to decrease the pore space within the concrete matrix. **Figure 6** showed that sorptivity value was 7.2% lower at 7 days in OPC concrete as compared with 5% RHASBABC concrete but at 90 days, it was 13.4% higher in OPC concrete than in 5% RHASBABC concrete. This explains that the initial setting time is slower in RHASBABC concrete which reflects its ability to precipitate carbonate in concrete microstructure. These findings revealed the effectiveness of pozzolanic content found in rice husk and sugarcane bagasse ashes, as their presence created an additional C-S-H gel that filled up void spaces within the concrete matrix.



(a)



(b)

Figure 6. (a) X-ray diffraction pattern of the control sample and (b) Plot of results; Quantitative analysis report for OPC concrete.

Table 4. Water absorption capacity in concrete samples.

	OPC Concrete (%)	5% RHASBABC Concrete (%)
7 DAYS	5.68	6.55
28 DAYS	5.67	6.41
96 DAYS	5.4	4.85

6. X-Ray Diffraction (XRD)

X-Ray diffraction studies were further conducted on samples to investigate the chemical and mineralogical components. Figure 6 and Figure 7 show the Result of XRD for OPC Concrete and 5% RHASBABC Concrete, indicating the micro-crystals of the inorganic which explained the mechanism behind their hydration performance. The number of peaks recorded was twenty-three for both samples and the angle of incidence was between 14.62 Å - 1.37 Å, interplanar spacing

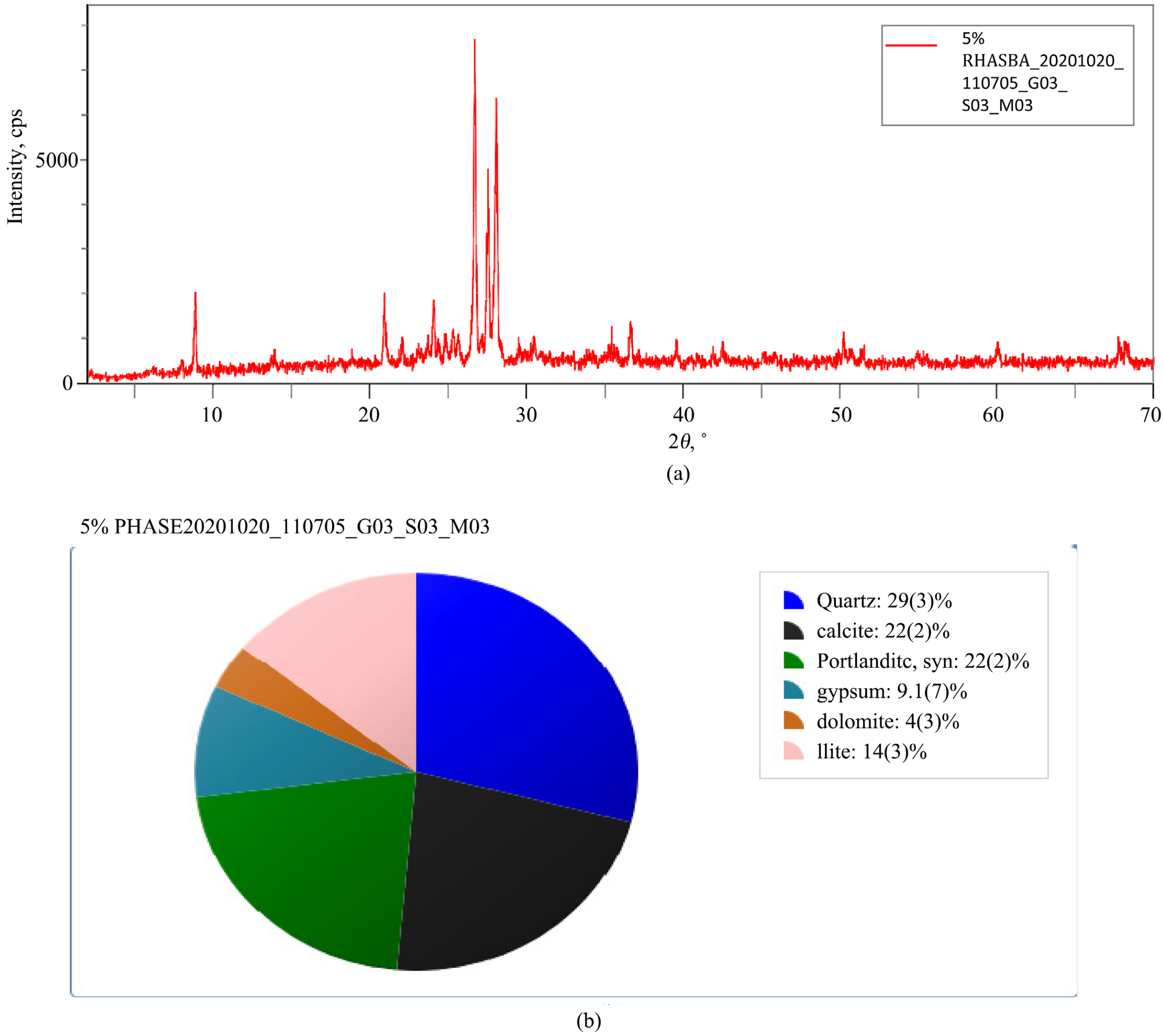


Figure 7. (a) X-ray diffraction pattern of the 5% RHASBABC sample and (b) Plot of results; Quantitative analysis report for 5% RHASBABC concrete.

range of 6.05 Å - 68.26 Å, the highest intensity observed was 100 cps for both samples. But the lowest intensity was 1.30 cps in 5% RHASBABC concrete while it was 0.86 cps for OPC concrete. Table 5 and Table 6 show the evaluation of quanlitative analysis report for OPC concrete and 5% RHASBABC concrete. The micro crystals of the inorganic Quartz (SiO_2), portlandite ($Ca(OH)_2$), goethite ($FeO(OH)$), Biotite, Plagioclase, Calcite were all identified by X-ray diffraction pattern for OPC concrete. Quartz, calcite, Portlandite, gypsum, dolomite, and illite were all identified in 5% RHASBABC concrete. From these findings, In the case of optimized RHASBABC blended concrete samples, XRD diffraction patterns displayed the presence of the majority of mineral gypsum, dolomite, and illite which is the main modification between the two figures. In agreement with that, the Quartz peaks have dropped down due to the participation of the SiO_2 in

Table 5. XRD qualitative analysis results evaluation report for OPC concrete.

Phase name	Formula	Figure of merit	Phase reg. detail
Quartz	SiO_2	1.674	S/M PDF-4 Minerals 2020 R…
portlandite	$Ca(OH)_2$	3.481	S/M PDF-4 Minerals 2020 R…
goethite	FeO(OH)	3.100	S/M PDF-4 Minerals 2020 R…
Biotite	$H_4K_2Mg_6Al_2Si_6O_{24}$	2.239	S/M PDF-4 Minerals 2020 R…
Plagioclase	$Ca_{0.66}Na_{0.34}Al_{1.66}Si_{2.34}$…	1.871	S/M PDF-4 Minerals 2020 R…
Calcite	$Ca(CO_3)$	3.160	Import PDF-4 Minerals 2020…

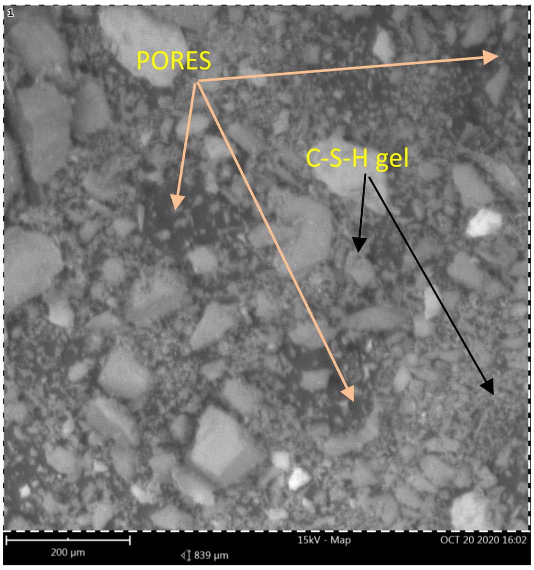
Table 6. XRD qualitative analysis results evaluation report for 5% RHASBABC concrete.

Phase name	Formula	Figure of merit	Phase reg. detail
Quartz	SiO_2	3.070	Import PDF-4 Minerals 2020…
calcite	$Ca(CO_3)$	3.229	Import PDF-4 Minerals 2020…
Portlandite, syn	$Ca(OH)_2$	2.886	Import PDF-4 Minerals 2020…
gypsum	$Ca(SO_4)(H_2O)_2$	3.134	Import PDF-4 Minerals 2020…
dolomite	$CaMg(CO_3)_2$	3.091	Import PDF-4 Minerals 2020…
Illite	$KAl_2Si_3AlO_{10}(OH)_2$	1.924	Import PDF-4 Minerals 2020…

the reaction with CaO to produce secondary C-S-H. This observation was expected since RHA and SBA have the highest SiO_2 and it could be said that the formation of calcium silicate hydrate increases in RHASBABC concrete. It was noted that the amount of $Ca(OH)_2$ reduce in RHASBABC concrete when compared with OPC concrete, because hydration process exploited $Ca(OH)_2$ produced during hydration and converted it to C-S-H in the concrete matrix, this is also in accordance with the result obtained by [19], who recognized that the degree of pozzolanic reaction in a blended cement mortar is related to the utilization of $Ca(OH)_2$.

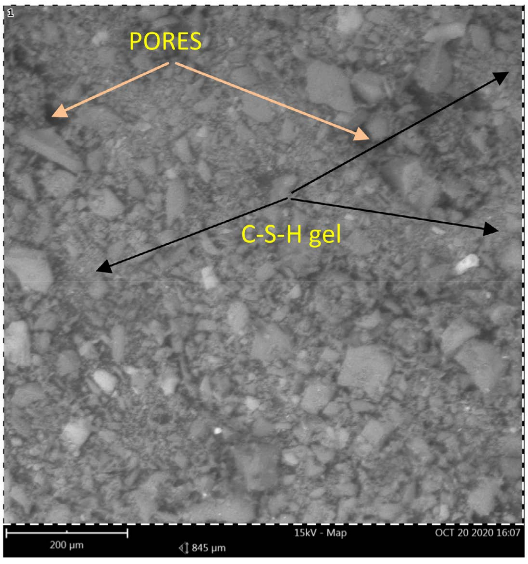
7. Scanning Electron Microscope (SEM)

The hydration behaviors of the concrete mixes were also studied using SEM. It was noted that by incorporating RHASBA in the concrete, the formation of calcium silicate hydrate was increased by consuming the calcium hydroxide content which acted negatively in the concrete matrix. It reacts with CO_2 to cause efflorescent leaving concrete vulnerable to attack. This phenomenon pointed out the reduction of $Ca(OH)_2$ crystals and filling up pore space with newly formed C-S-H compound leading to strengthening of bond between the cementing materials and aggregates. It is very evident that SEM image of OPC concrete show's higher porous structure compared to the image of 5% RHASBABC concrete. This means incorporating RHASBA in a concrete mixture enhances the density and enrich microstructural element which in turn improve the compressive strength of concrete. **Figure 8** and **Figure 9** show the elements found in the two



Element Number	Element Symbol	Element Name	Atomic Conc.	Weight Conc.
14	Si	Silicon	41.81	33.20
20	Ca	Calcium	16.80	19.04
26	Fe	Iron	10.40	16.42
19	K	Potassium	8.77	9.69
13	Al	Aluminium	9.14	6.97
22	Ti	Titanium	2.16	2.93
47	Ag	Silver	0.69	2.11
23	V	Vanadium	1.15	1.66
41	Nb	Niobium	0.54	1.41
11	Na	Sodium	1.92	1.25
39	Y	Yttrium	0.50	1.25
17	Cl	Chlorine	1.18	1.18
16	S	Sulfur	1.05	0.96
12	Mg	Magnesium	1.18	0.81
6	C	Carbon	2.33	0.79
15	P	Phosphorus	0.38	0.34

Figure 8. SEM showing an element in OPC concrete sample. FOV: 839 µm; Mode: 15 kV - Map; Detector: BSD Full; Time: OCT 20 2020 16:02.



Element Number	Element Symbol	Element Name	Atomic Conc.	Weight Conc.
14	Si	Silicon	45.93	36.97
20	Ca	Calcium	17.31	19.88
26	Fe	Iron	8.47	13.56
19	K	Potassium	11.90	13.33
13	Al	Aluminium	9.75	7.54
47	Ag	Silver	0.76	2.35
39	Y	Yttrium	0.57	1.45
41	Nb	Niobium	0.43	1.15
16	S	Sulfur	0.97	0.89
11	Na	Sodium	1.25	0.82
22	Ti	Titanium	0.60	0.82
12	Mg	Magnesium	0.97	0.68
15	P	Phosphorus	0.33	0.29
6	C	Carbon	0.76	0.26

Figure 9. SEM showing element in 5% RHASBABC concrete sample. FOV: 845 µm; Mode: 15 kV - Map; Detector: BSD Full.

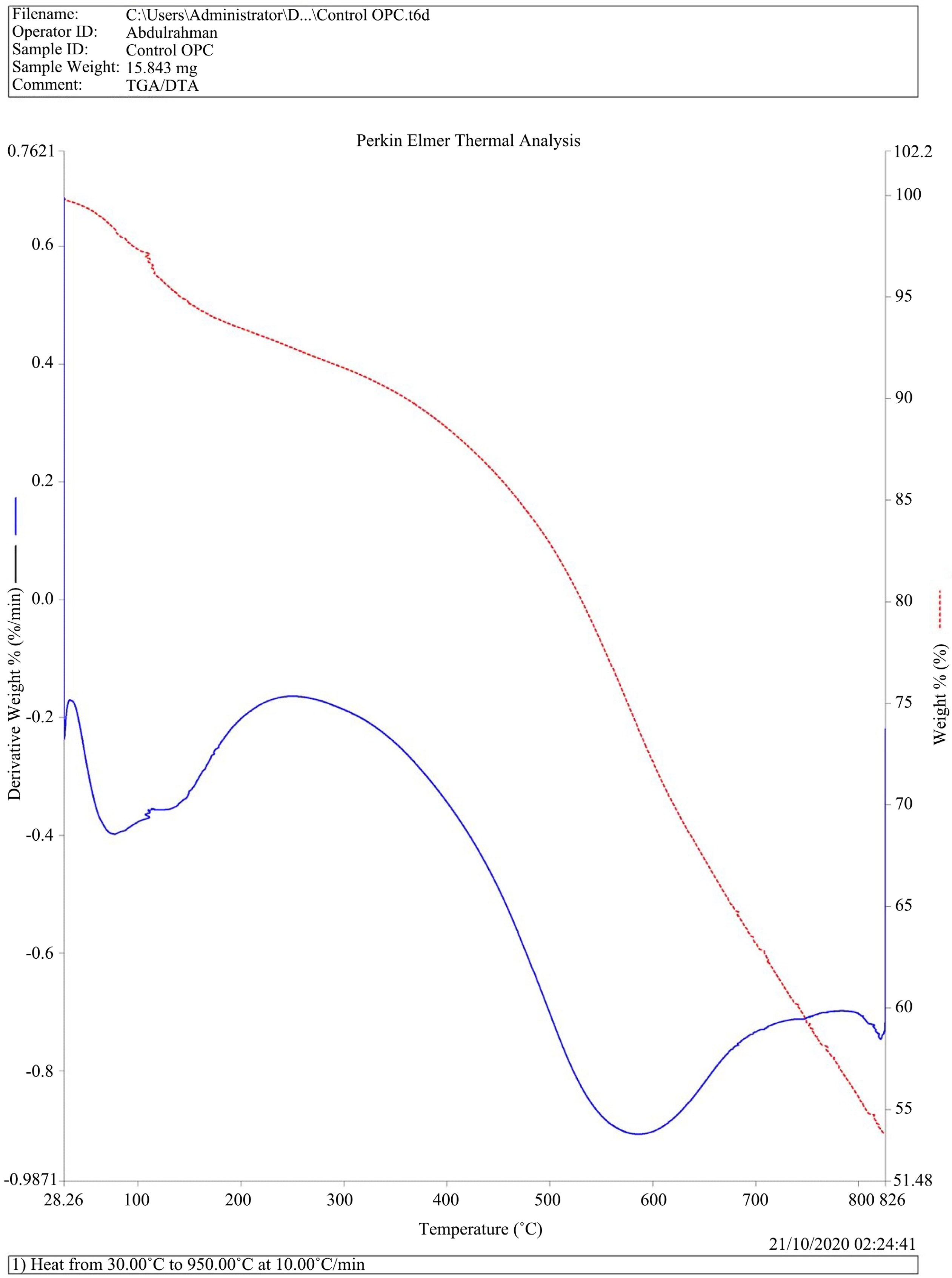


Figure 10. Thermo-Gravimetric Analysis (TGA) and differential thermal analysis for OPC concrete.

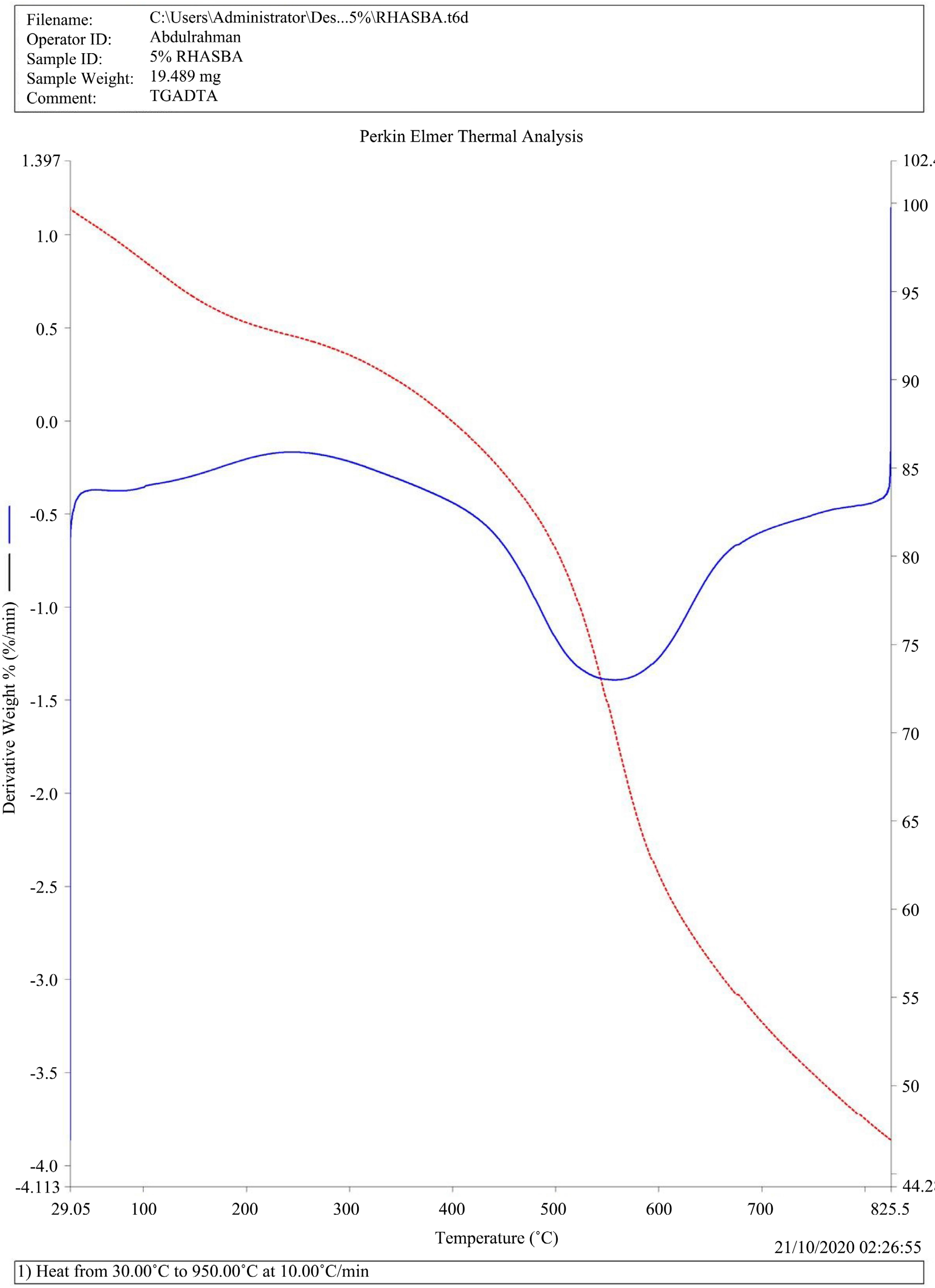


Figure 11. Thermo-Gravimetric Analysis (TGA) and differential thermal analysis for 5%RHASBA concrete.

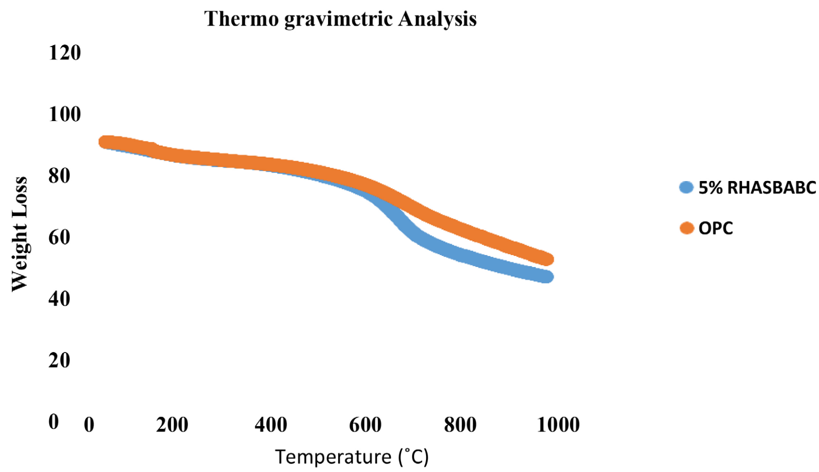


Figure 12. Superimposed result of TGA for OPC concrete and 5% RHASBABC.

samples. Silicon contents are higher in 5% RHASBABC concrete compared with OPC concrete and also, there is the low level of Calcium found in 5% RHASBABC concrete when compared with OPC concrete. This implies that RHASBA is a pozzolanic material that could react with lime during hydration of cement to produce an additional calcium silicate hydrate (C-S-H) and also subjugated $Ca(OH)_2$ during hydration and convert it to C-S-H in a concrete mix. Similar result was gotten by [20], in his experiment involving "fire resistance evaluation of rice husk ash concrete". The authors opined that additional calcium silicate hydrates (C-S-H) formed from the cement-pozzolan reactions were responsible for the improved post-fire residual strength of the concrete.

Thermo - Gravimetric Analysis **(TGA) and Differential Thermal Analysis**

Two samples were analyzed by thermo-gravimetric analysis (TGA) which was subjected to temperature ranges. Samples were put in a ceramic crucible and heated from room temperature to 850˚C in a thermal analyzer. **Figure 10** and **Figure 11** indicate the small quantities of hydrate at different temperatures which were aimed to evaluate the thermal stability of OPC concrete and 5% RHASBABC concrete to determine the heat flow, mass loss (%) and temperature relationship of the two samples. Weight loss was observed in both samples as temperature increases from 25˚C to 105˚C, which shows loss of free water within the pore space of the concrete. At the temperature of 105˚C to 400˚C, it was dehydration of C-S-H that took place and when the temperature was increased from 400˚C to 600˚C, de-hydroxylation of portandite occurred. The final stage occurs when temperature was increased from 600˚C to 800˚C, which resulted in decarbonation of $CaCO_3$. The total weight loss in 5% RHASBABC concrete was lowered compared to weight loss in OPC concrete as shown in **Figure 12**. It could be concluded that C-S-H gel and calcium aluminate hydrate were found in concrete containing RHASBA content and also have better resistance to heat.

8. Conclusions

Following the results from this study, RHASBA has a pronounced potential as partial substitute for cement in concrete production and the following conclusions may be drawn;

1) RHA and SBA are enriched with SiO_2 which allows for more reaction in concrete mix.

2) The optimum partial replacement of cement in this study was 5% RHASBA, which yielded 15% increase in compressive strength and 3.4% increase in flexural strength than that of control concrete. At 7 days, the strength development was slower in 5% RHASBABC concrete but was later increased with age. This was an indication that RHASBABC concrete needed more curing days for its strength development in concrete.

3) Sorptivity value was progressively lowered in concrete made of 5% RHASBABC as compared with conventional concrete. It was established that the addition of RHASBA to cement in concrete, lowered the sorptivity, thereby increasing the compressive strength by reducing the pore spaces in the concrete matrix as was observed in the scanning electron microscope test.

4) The presence of RHASBA in concrete mixture lowered chloride ion penetration because fewer charges passed through concrete with RHASBABC (1125) as compared with control concrete (2525). The lower the chloride ion penetration, the lesser the porosity and also lower the rate of permeability, which improves the strength properties of concrete.

5) The microstructure studies revealed a clear indication of the C-S-H gel development in 5% RHASBABC concrete sample, which extremely improve the compactness by refining the microstructure of the concrete and filling up the pore spaces, which helped enhance the hardened properties of the concrete, making the concrete durable and less permeable.

6) TGA results were in support of RHASBABC concrete. The responses to temperature differences were the same with control concrete up to the 400˚C. Beyond this point, strength of concrete depreciates rapidly due to degradation of C-S-H. It was observed that more weight was lost in 5% RHASBABC concrete sample compared with the control concrete within 500˚C - 1000˚C. This was an indication that 5% replacement of cement by RHASBA improved the concrete features.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Jung, S.H., Saraswathy, V., Karthick, S., Kathirvel, P. and Kwon, S.-J. (2018) Microstructure Characteristics of Fly Ash Concrete with Rice Husk Ash and Lime Stone Powder. *International Journal of Concrete Structures and Materials*, **12**, Article No. 17. https://doi.org/10.1186/s40069-018-0257-4

[2] Ye, G., Huang, H. and Van Tuan, N. (2018) Rice Husk Ash. In: De Belie, N., Soutsos, M. and Gruyaert, E., Eds., "*Properties of Fresh and Hardened Concrete Con-*

taining Supplementary Cementitious Materials": *State-of-the-Art Report of the RILEM Technical Committee* 238-*SCM*, *Working Group* 4, Springer International Publishing, Cham, 283-302.

[3] Ganesan, K., Rajagopal, K. and Thangavel, K. (2008) Rice Husk Ash Blended Cement: Assessment of Optimal Level of Replacement for Strength and Permeability Properties of Concrete. *Construction and Building Materials*, **22**, 1675-1683. https://doi.org/10.1016/j.conbuildmat.2007.06.011

[4] Hossain, K.M.A. and Anwar, M.S. (2014) Performance of Rice Husk Ash Blended Cement Concretes Subjected to Sulfate Environment. *Magazine of Concrete Research*, **66**, 1237-1249. https://doi.org/10.1680/macr.14.00108

[5] Raheem, A.A. and Kareem, M.A. (2017) Chemical Composition and Physical Characteristics of Rice Husk Ash Blended Cement. *International Journal of Engineering Research in Africa*, **32**, 25-35. https://doi.org/10.4028/www.scientific.net/JERA.32.25

[6] Bahurudeen, A., Kanraj, D., Dev, V.G. and Santhanam, M. (2015) Performance Evaluation of Sugarcane Bagasse Ash Blended Cement in Concrete. *Cement and Concrete Composites*, **59**, 77-88. https://doi.org/10.1016/j.cemconcomp.2015.03.004

[7] Jagadesh, P., Ramachandramurthy, A., Murugesan, R. and Prabhu, T.K. (2019) Adaptability of Sugar Cane Bagasse Ash in Mortar. *Journal of the Institution of Engineers* (*India*): *Series A*, **100**, 225-240. https://doi.org/10.1007/s40030-019-00359-x

[8] Bin Muhit, S., Ahmed, S., Zaman, Md.F. and Ullah, Md.S. (2018) Effects of Multiple Supplementary Cementitious Materials on Workability and Strength of Lightweight Aggregate Concrete. *Jordan Journal of Civil Engineering*, **12**, 109-124.

[9] NIS 444, Part 1 (2003) Composition, Specifications and Conformity Criteria for Common Cements. Nigeria Industrial Standards Center.

[10] ASTM, C136-06 (2006) Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates. ASTM International, West Conshohocken.

[11] BS 882 (1992) Aggregates from Natural Sources. British Standard, London.

[12] ASTM C618-19 (2019). Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete. American Society for Testing and Materials International, West Conshohocken.

[13] BS EN 12350-2 (2009) Testing Fresh Concrete. Slump-Test. British Standard, London.

[14] ASTM C293/C293M-16, "Standard Test Method for Flexural Strength of Concrete Using Simple Beam with Center-Point Loading. American Society for Testing and Materials, United States.

[15] Naji, A., Abdul, S., Nora, F., Aziz, A., Amran, M. and Salleh, M. (2010) Assessment of the Effects of Rice Husk Ash Particle Size on Strength, Water Permeability and Workability of Binary Blended Concrete. *Construction and Building Materials*, **24**, 2145-2150. https://doi.org/10.1016/j.conbuildmat.2010.04.045

[16] Younes, M.M. and Khattab, M.M. (2018) Utilization of Rice Husk Ash and Waste Glass in the Production of Ternary Blended Cement Mortar Composites. *Journal of Building Engineering*, **20**, 42-50. https://doi.org/10.1016/j.jobe.2018.07.001

[17] Moeeni, S.A., Imam, A. and Srivastava, V. (2017) A Review on the Effect of Rice Husk Ash Blending on Concrete Properties, (November).

[18] Leong, S.W., Sih Ying, K., Ahmed Farid, M., Dawood, M.I., Esam Abdalslam, E.E. and Praveen, R. (2022) Surface Treatment of Concrete by Calcium Carbonate Biodeposition Using *Candida orthopsilosis*. *Jordan Journal of Civil Engineering*, **16**,

33-53.

[19] Rukzon, S. and Chindaprasirt, P. (2012) Utilization of Bagasse Ash in High-Strength Concrete. *Materials and Design*, **34**, 45-50. https://doi.org/10.1016/j.matdes.2011.07.045

[20] Umasabor, R.I. and Okovido, J.O. (2018) Fire Resistance Evaluation of Rice Husk Ash Concrete. *Heliyon*, **4**, E01035. https://doi.org/10.1016/j.heliyon.2018.e01035