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Review Article

Effect of Agricultural Crop Wastes as Partial Replacement of Cement in Concrete Production

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The main goal of this review paper was to study the physical and chemical properties of agricultural crop wastes and their potentials to partially replace in production of mortar and concrete. Bamboo leaves' ashes (BLA), banana leaves' ashes (BNLA), corncob leaves' ashes (CCA), groundnut ashes (GNA), rice husk ashes (RHA), and sugarcane bagasse ashes (SCBA) were selected to be reviewed. The chemical composition of these agricultural wastes revealed that the they are basically composed of alumino-siliceous materials conforming the requirement of pozzolanic materials. Compared with cement, they have finer particle size and higher surface area. The effect of partial replacement of cement by BLA, BNLA, CCA, GNA, RHA, and SCBA on the properties of fresh concrete (consistency, workability, and setting time), mechanical properties (compressive and tensile strength), microstructure (scanning electron microscopy, derivative thermogravimetry, and X-ray diffraction), and durability (ultrapulse velocity, water absorption, and sulphate attack) of concrete was recapped. The inclusion of BLA, CCA, RHA, and SCBA as partial replacement of cement reduced the workability of concrete due to their finer particle size. The mechanical performance of concrete showed enhancement with partial replacement of cement by BLA, RHA, and SCBA due to the involvement of amorphous silica in secondary reaction to produce densified tetrahedral gel. Consequently, uniform and denser morphology was formed, and durability was enhanced as densification of hydrated gel increased. In general, the review exposed that agricultural crop wastes satisfy pozzolanic material properties and have strong potential to replace cement up to 10% without compromising the performance of concrete.

1. Introduction

The world concern about both environmental degradation and greenhouse gas emissions stressed the significance of research in finding new sustainable alternatives to some products, among them Portland cement (OPC), and it is well known that pozzolans improve the mechanical behavior and durability of cementitious matrices by acting chemically and physically [1]. Concrete is the largest volume material used by humans and is irreplaceable for large infrastructure developments. The success of concrete comes from, on the one hand, the broad accessibility and low cost of its components and, on the other hand, the means with which it can be prepared. Every year, more than 1 m^3 of concrete is produced per person worldwide with Portland cement being the crucial ingredient, but producing the topmost environmental burden. Presently, around 3 billion tons of Portland cement are consumed worldwide, and for the production of every 600 kg of cement, roughly, 400 kg of carbon dioxide gas is released, around 5–8% of all manmade CO_2 [2, 3].

Presently, China produces over half of the world's cement universally by a large periphery, at an estimated 2.2 billion metric tons in 2019, followed by India at 320 million metric tons in the same time. Global cement product is anticipated to increase from 3.27 billion metric tons in 2010 to 4.83 billion metric tons in 2030. It was estimated that the cement production increased by 84% from 2001 to 2018 [4].

According to the Intergovernmental Panel on Climate Change [5] report, the impact of global warming of 1.5°C above the preindustrial situations and its related global greenhouse gas emission (GHG) problems ultimately leads the world to establishment of strong global response to the trouble of climate change, sustainable development, and the efforts to eliminate poverty. The report indicates the greenhouse gas (GHG) emissions of CO_2 from cement product unexpectedly increased in the last 100 years.

It is known that the ceaseless generation of solid waste materials represents serious environmental and technical problems. Also, the valuation of the pozzolanic action of cement replacement materials is becoming increasingly important because of the need for further sustainable cementing products. Pozzolans materials are supplementary cementitious materials derived from industrial and agricultural wastes and possess pozzolanic properties in concrete production. In recent years, the use of solid waste resulting from agriculture as pozzolans in the manufacture of blended mortars and concrete has been the focus of new researches [6–13], and they have been showed that agricultural waste products could be a partial replacement material to cement and aggregates in concrete and mortar. Cotton stalk ash (CSA) and palm leaf ash (PLA) had higher specific gravity and surface area, and the inclusion of it in concrete as recycled aggregates and light-weight coarse aggregate (LWCA) in concrete would be the unit weight of concrete [14, 15]. The addition of CSA up to 10% of LWCA improved the mechanical performance of concrete. The application and replacement of rice hush ash (RHA), rice straw ash (RSA), and nano-rice husk ash (NRHA) in cement concrete at various percentages increased the durability and mechanical performance of light-weight self-compacting concrete [14, 16, 17]. The other pozzolans that could be used as supplementary cementitious material in concrete were olive waste ash (OWA) and palm oil fuel ash; they contain the basic chemical compositions of OPC, and CaO and SiO_2 were the major compounds with the highest content [12, 18, 19]; in addition, the 28-day target compressive strength was almost met with 5% OWA [17].

The generation and management of waste is an issue of vital significance for economic and environmental development and has direct implications for sustainability in the twenty-first century. Agrowastes are produced worldwide in huge amounts, and they contain interesting elements for producing inorganic cementing binders, especially silicon. Silica-rich ashes are preferred for preparing inorganic binders [20].

Ecological or environmental benefits of indispensable supplementary materials include the diversion of nonrecycled waste from landfills for useful operations and the reduction in the negative effects of producing cement powder, namely, the consumption of nonrenewable natural resources, the reduction in the use of energy for cement production, and the corresponding emission of greenhouse gasses reduction in the use of energy for cement production and the corresponding emission of greenhouse gasses [3]. The production of agricultural foods becomes the major source for the need of human beings, and the waste production of these cereal crops has been dumped in unwanted landfills and greatly affects the ecosystems of the planet.

The main aim of this review paper is to recap and analyze the potential of agricultural wastes as partial replacement of cement and its effect on the fresh, mechanical, microstructure, and durability properties of concrete.

2. Literature Review

2.1. Material Characterization

2.1.1. Chemical Compositions. Bamboo leaves' ash is obtained from the waste of bamboo plant leaves deposited on earth. The leaves are collected from bamboo plant farms from different areas of Brazil and Cuba. Then, they were burned at a temperature between 400°C and 600°C and calcined in a muffle furnace at higher heating rate of 100 C/min to remove organic matters within the leaves' ashes. The method used by different researchers to identify the chemical compositions of bamboo leaves' ashes was X-ray fluorescence (XRF). According to the researchers, more than 70% of the oxides of bamboo leaves' ash was silica (SiO_2, Al_2O_3, and Fe_2O_3) followed by a significant amount of CaO, SO_3, and LOI. The other results of the chemical compositions of BLA by Abebaw et al. [21] revealed that SiO_2, CaO, and Al_2O_3 were the main oxides, and the LoI was recorded as 9.65%. Asha et al. [22] confirm that BLA had 59.20% silicon dioxide which confirms that it has the potential of acting as a pozzolanic material. Table 1 summarizes the chemical compositions of BLA based on Frías et al. [23]; Rodier et al. [24]; Villar-Cociña et al. [25]; Moraes et al. [1]; Villar-Cociña et al. [26]; and Abebaw et al. [21]. According to the table and the oxide compositions, all the BLA samples would comply with [27] and characterizes as pozzolans with class N. The higher LOI recorded [1] might be due to the soil and its fertility to grow the bamboo plant and species. The LOI indicates that there may be some organic matter in the BLA and there needs further calcining.

Based on the parameters, experiments, and data gained from different literature reviews [28–35], banana leaves' ashes (BLNA) were obtained by subsequently burning the leaves at 900°C for 24 h in air. Kanning et al. [36] and Dhage et al. [37] investigated the chemical compositions of banana leaves' ash (BNLA) with the aid of X-ray fluorescence (XRF) test method for which BNLA was collected from Brazil and India. The banana leaves were calcined at a temperature of 900°C for 24 h in air. The XRF result showed that the chemical compositions of BLA mainly constitute from SiO_2, Al_2O_3, and Fe_2O_3 and some amounts of loss on ignition (LOI) and Na_2O. The total silicious material content was less than 70% (52.7% and 51.80%), LOI was more than 5% and [27] classified the BLA as class F pozzolanic materials. The chemical compositions are summarized in Table 2.

In 2020, it was estimated that the world's total maize production was 1.03 million thousand tons, and in 2019, the world maize producers allocated 192 mil ha of the sown area,

Table 1: Chemical compositions of bamboo leaves' ashes (BLA).

Chemical compositions (%)	Authors					
	Frías et al. [23]	Rodier et al. [24]	illar-Cociña et al. [25]	Moraes et al. [1]	Villar-Cociña et al. [26]	Abebaw et al. [21]
SiO_2	78.71	70.50	80.40	74.23	73.46	65.66
Al_2O_3	1.01	0.63	1.22	2.27	0.13	6.41
Fe_2O_3	0.54	0.47	0.71	2.34	0.41	4.28
CaO	7.82	7.86	5.06	3.30	4.31	15.22
MgO	1.83	1.84	0.99	1.46	3.28	2.48
SO_3	1.00	2.87	1.07	0.84	4.21	
K_2O	3.78	5.11	1.33	2.11	5.42	4.84
Na_2O	0.05	ND	0.08	ND	0.45	2.76
P_2O_5	0.99	1.67	0.56	1.02	1.84	
Cl	ND	0.85	ND	0.39	0.51	
Others	0.44	0.41	0.50	0.70	0.94	
LOI	2.83	7.79	8.08	11.34	5.56	9.65
$SiO_2 + Al_2O_3 + Fe_2O_3$	**80.26**	**71.60**	**82.33**	**78.84**	**74.00**	**76.35**

Table 2: Chemical composition of banana leaves' ashes (BNLA).

Authors	Chemical compositions (oxides %)					$SiO_2 + Al_2O_3 + Fe_2O_3$
	SiO_2	Al_2O_3	Fe_2O_3	Na_2O	LOI	
Kanning et al. [36]	48.70	2.60	1.40	0.21	5.06	52.70
Olutaiwo and Olushola [33]	47.24	2.71	0.85	0.00	16.90	50.80
Pawar and Aman [34]	48.70	2.60	1.40	0.21	5.06	52.70
Musthafa et al. [35]	48.70	2.60	1.40	0.21	5.06	52.70
Dhage et al. [37]	47.80	2.60	1.40	0.21	5.06	51.80

Table 3: Chemical composition of corncob leaves' ashes (CCA).

Chemical compositions (oxides %)	Authors					
	Adesanya and Raheem [40, 41]	Owolabi et al. [42]	Singh et al. [43]	S.A. Memon et al. [44]	Desai [45]	Bheel and Adesina [46]
Country	Nigeria	Nigeria	India	Pakistan	Gujarat	Pakistan
SiO_2	66.38	64.90	64.56	63.73	62.30	67.23
Al_2O_3	7.48	10.79	9.42	15.08	6.25	6.34
Fe_2O_3	4.44	4.75	5.12	5.32	4.40	5.33
CaO	11.57	10.24	12.00	6.56	10.57	10.75
MgO	2.06	2.08	3.01	4.56	1.86	ND
SO_3	1.07	2.53	ND	ND	1.02	1.04
K_2O	4.92	4.30	ND	2.05	3.89	5.42
Na_2O	0.41	0.43	ND	0.10	0.36	0.37
Others	1.67	—	5.89	2.60	9.35	3.52
$SiO_2 + Al_2O_3 + Fe_2O_3$	**78.30**	**80.44**	**79.10**	**84.13**	**72.95**	**78.90**

which was 3 million more than in 2018 [38, 39]. According to the report of US, China, Brazil, Argentina, and Ukraine have been the leading maize-producing countries in the world and account for about 75.18% of production. Corncob ashes (CCA) have become one of the potential agricultural waste products of pozzolanic materials to be replaced with cement partially [40–45]. The test result of the chemical compositions made with X-ray fluorescence (XRF) and energy dispersive X-ray spectroscopy (EDS) conducted by the researchers is shown in Table 3. It indicates that the total sum of chemical compositions of SiO_2, Al_2O_3, and Fe_2O_3 was more than 70% and the maximum contents of SO_3 were less than 4%, so that it could be classified as class N pozzolanic materials by ASTM C 618–19.

So many research studies have been conducted on the evaluation of the use of ground nut ash (GNA) as partial replacement materials for cement. According to [47–49], the environmental burden vast waste disposal problems caused by the deposition of groundnut shell has been minimized by the use of GNA. The chemical composition analysis evaluated by Usman et al. [50] and Buari et al. [51] with X-ray fluorescence (XRF) for GNA showed that the amount of SiO_2 was about 30%, Al_2O_3 was between 10% and 16%, and Fe_2O_3 varied from 5% to 14%. A contrast GNA amount of oxides was investigated by Nwofor and Sule [52]. They found that the total oxide content of silicious compounds was less than 25%, i.e., Fe_2O_3 (1.80%), SiO_2 (16.21), and Al_2O_3 (5.93%). Table 4 shows the LOI values proving there was a

Table 4: Chemical composition of groundnut leaves' ashes (GNA).

Chemical compositions (oxides %)	Authors		
	Nwofor and Sule [52]	Usman et al. [50]	Buari et al. [51]
Country	Nigeria	Nigeria	Nigeria
SiO_2	16.21	31.80	32.60
Al_2O_3	5.93	10.12	16.02
Fe_2O_3	1.80	5.03	14.21
CaO	8.69	20.79	8.69
MgO	6.74	8.77	2.74
SO_3	6.21	2.46	1.21
K_2O	15.75	2.07	18.73
Na_2O	9.02	0.09	0.04
LOI	—	7.95	4.20
$SiO_2 + Al_2O_3 + Fe_2O_3$	**23.94**	**46.95**	**62.83**
ASTM standard	Not satisfied	Not satisfied	Class C

Table 5: Chemical compositions of rice husk ashes (RHA).

Authors	Chemical compositions (oxides %)									$SiO_2 + Al_2O_3 + Fe_2O_3$
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	K_2O	Na_2O	LOI	
Khan et al. [56]	86.80	0.895	2.435	0.45	0.55	—	—	—	2.5	90.08
Antiohos et al. [57]	86.50	0.92	0.56	1.12	1.30	0.05	1.58	0.43	6.3	87.98
Raheem and Kareem [58]	82.14	1.34	1.27	1.21	1.37	0.17	2.09	0.14	—	84.75
Zareei et al. [59]	86.70	0.04	0.61	0.39	1.32	9.8	0.01	—	—	87.38
Krishna et al. [60]	76.8	0.41	1.045	0.93	0.27	—	2.64	0.1	—	78.22
Abiodun and Jimoh [61]	61.33	2.20	8.43	6.53	2.33	—	11.90	2.53	—	71.97
Salas et al. [62]	90.00	0.68	0.42	8.14	0.35	—	—	0.32	—	91.10
Faried et al. [13, 16]	70.36	1.54	0.68	4.51	1.35	3.23	8.73	1.09		72.58

large amount of unburned organic matter within the GNA. According to the table, in all cases, the total percentage of iron oxide (Fe_2O_3), silicon dioxide (SiO_2), and aluminum oxide (Al_2O_3) is found to be less than the minimum of 70% specified for pozzolanas by [27] to characterize as class N and class F. The chemical oxide compositions obtained were confirmed with the oxide's compositions reported by Ndefo [53], Nwofor and Sule [52], and Rathod and Mahure [54]. However, in the case of Usman et al. [50] and Buari et al. [51], the percentage content of sulfur trioxide was found to be much lower than the maximum recommended (5%).

Different studies have shown that silica, alumina, and iron oxide are the main chemical oxides of rice husk ash (RHA). Rice husk, an agro waste material, contains about 20% ash which can be retrieved as amorphous and chemically reactive silica [55]. The X-ray fluorescence spectrometer (XRF) laboratory results tabulated in Table 5 revealed the oxides of RHA. It indicates the sum of silicious oxides (SiO_2, Al_2O_3, and Fe_2O_3) is much greater than 70% and fulfills the requirements to be used as pozzolanic cementitious materials. Based on Table 5, RHA can be classified as Class N pozzolanic material satisfying ASTM C 618—19 standard requirements. The chemical composition values obtained in the clinker were agreed with the values reported by Bouzoubaâ and Fournier [63]; Hossain [64]; and Turanli et al. [65]. Faried et al. [13, 16] identified the chemical compositions of nano-rice husk ash (RHA) by calcining at different temperatures from 300°C to 900°C. They examined that the silicious contents of the RHA samples were significantly increased with increasing burning degree. The average chemical compositions are listed in Table 5.

Table 6: Mineral oxides of SCBA conducted by various authors.

Authors	Country	Chemical compositions (%)			
		SiO_2	CaO	Fe_2O_3	Al_2O_3
Khan et al. [67]	India	78.40	2.14	3.62	8.40
Loganayagan et al. [68]	India	62.00	0.48	1.79	31.50
de A Mello et al. [69]	Brazil	75.58	1.79	9.91	2.50
Abbas et al. [70]	Pakistan	80.45	2.73	2.38	7.19
Rodier et al. [24]	Brazil	36.20	7.10	8.70	12.30
Rajasekar et al. [71]	India	86.79	3.42	1.75	2.45
Zareei et al. [72]	Iran	64.23	8.17	5.47	9.08
Ríos-Parada et al. [73]	Mexico	66.12	2.57	7.16	15.00
Ferreira et al. [74]	Brazil	41.10	4.00	15.70	24.10
Patel and Raijiwala [75]	India	58.62	1.92	12.25	14.95
Kawade et al. [76]	India	66.89	1.92	—	29.18
Teixeira et al. [77]	Brazil	77.50	2.30	3.80	4.70

As X-ray efflorescence (XRF) has been the common laboratory methods used to analyze the chemical oxides of pozzolanic materials, it was used to identify the oxides contents of sugarcane bagasse (SCBA). In the review made by Quedou et al. [66] in the SCBA, the mineral proportions were varied from country to country and the percentages of elements obtained by different authors in each sample of SCBA is shown in Table 6.

The results investigated by Ganesan et al. [78], Abd Elhameed Hussein et al. [79], Mangi et al. [80], and Quedou et al. [66] which are presented in Table 7 show that SCBA is

Table 7: Chemical compositions of SCBA.

Chemical oxides (%)	Authors			
	Quedou et al. [66]	Ganesan et al. [78]	Abd Elhameed Hussein et al. [79]	Mangi et al. [80]
SiO_2	30.27	64.15	77.25	65.00
Al_2O_3	23.80	9.05	6.37	3.95
Fe_2O_3	4.87	5.52	4.21	9.17
CaO	1.69	8.14	4.05	12.60
MgO	1.37	2.85	2.61	0.60
SO_3	—	—	0.11	0.10
K_2O	—	1.35	2.34	—
Na_2O	—	0.92	1.38	—
LOI	5.43	4.90	1.4	9.02
$SiO_2 + Al_2O_3 + Fe_2O_3$	**58.94**	**78.72**	**87.83**	**78.12**
ASTM class	Class C	Class F	Class F	Class N

composed of mainly SiO_2 (30.27% to 77.25%), Al_2O_3 (3.95% to 23.80%), and Fe_2O_3 (4.21% to 9.17%) with some significant oxides CaO, MgO, K_2O, and Na_2O. The reason for the presentation of high amount of loss on ignitions (LOI) is the duration and heating temperatures during burning and calcinations, and this might lead to reduction in the strengths of the concrete made with SCBA. Based on the pozzolanic materials classifications of [27], the total sum silicious materials (min %) and LOI (max %) indicates that the examined SCBA samples are classified as class N [80], class F [78, 79], and class C [66].

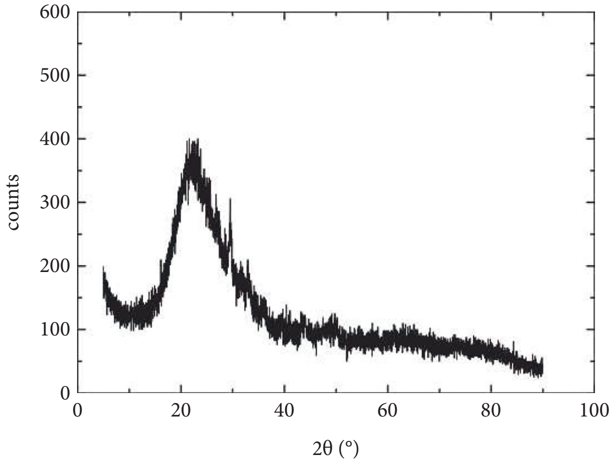


Figure 1: XRD pattern of bamboo leaf ash [25].

2.1.2. Characterizations of Pozzolanic Materials. The standard and the commonly used method to examine the mineralogical and morphological behavior of pozzolans materials has been X-ray diffraction (XRD) and scanning electron microscopy (SEM). Frías et al. [23], Villar-Cociña et al. [26], and Abebaw et al. [21] used XRD by using the random powder method to identify the mineralogical compositions of BLA. Figure 1 shows the mineralogical compositions of bamboo leaves calcined at 600°C for 2 hrs. According to the figure, a highly amorphous nature of BLA was detected with the broadband localized about 2θ of 20°–30°. The XRD pattern of BLA is similar to that of silica fume, which is a decidedly reactive pozzolan that is used mostly for high performance concrete manufacture [23, 25]. The main crystalline components were calcite ($CaCO_3$) followed by traces of cristobalite (SiO_2) and calcium sulphate ($CaSO_4$). The combination of SEM and EDX techniques confirmed that, after 28 days, the C-S-H gels in BLA/$Ca(OH)_2$ show irregular forms with very small dimensions. The same temperature was used by Villar-Cociña et al. [26] to calcine the bamboo leaves, and the ashes were obtained in a laboratory electric furnace at 400°C for 60 min to remove organic matter, and finally, they were calcined using an electric furnace at 500°C, 600°C, and 700°C, for a period of 2°h, with a heating rate of 10°C min^{-1}. Abebaw et al. [21] calcined BLA for 2 h at 600°C, the ash has dark grey color, 2.15 g/cc specific gravity, fineness modulus of 30.50%, and 1217 kg/m^3 density. The scanning electron microscopy (SEM) result showed that BLA had amorphous nature morphology [23, 26]. Rodier et al. [24] studied the potential use of bamboo leaves' ash and sugarcane bagasse ash as cementitious materials. Primarily, they calcined the bamboo leaves at 400°C for 60 min to remove organic matter and then calcined the leaves at 600°C for 60 min with a heating rate of 10°C/min. They found that BLA has a fine particle size with a median size of 21.41 μm. The Rigaku Miniflex 600 X-ray Diffractometer test result showed BLA has a characteristic of amorphous silica material and due to the highest calcining temperature, the quartz was found as the main crystalline mineral. In control, calcium hydroxide, quartz, calcite, alite, and C-S-H are identified. Villar-Cociña et al. [25] determined the bamboo leaves' ash was formed by silica with a completely amorphous nature and a high pozzolanic activity.

The bamboo leaves were dried in the sun and calcined in a laboratory electric furnace at 600°C temperature for 2 h. Of retention, in order to get the ashes, it gave grey color [25]. The ashes have fine granulometry with grain size between 1 and 100 μm and average size (D_{50}) of 58.1 μm. The mineralogical characteristics were studied using a X-ray diffractometer Phillips MPD 1880). According to the XRD result, the BLA shows a highly amorphous nature. Based on the detailed observations made by SEM (FEI Quanta 600 FEG) in Figures 2 and 3, it shows a regular morphology with some smooth surfaces' particles on the top of it and the C-S-H gels

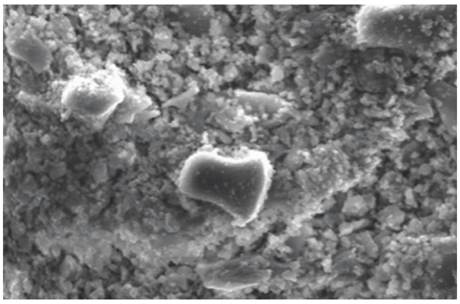


Figure 2: Morphology of bamboo leaf ash [25].

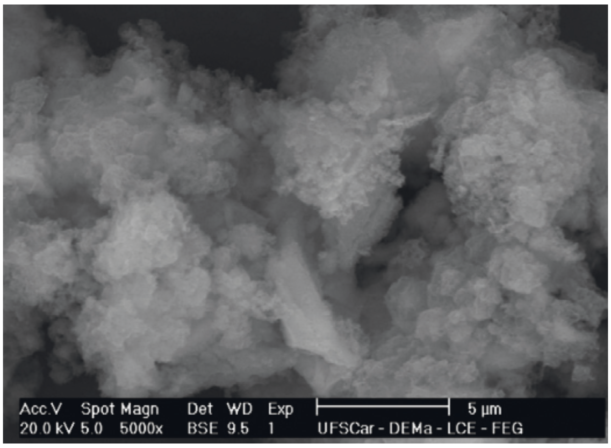


Figure 3: SEM C-S-H gel morphology of bamboo leaves' ashes [25].

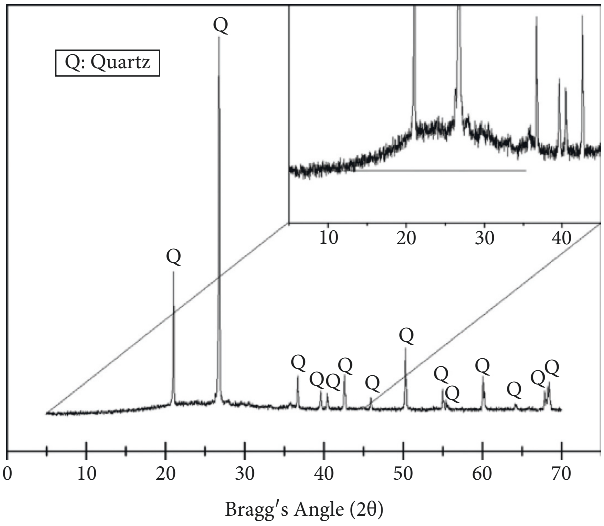


Figure 4: XRD pattern of bamboo leaf ash. [1].

show rough zones having a sponge-like morphology. The band form of BLA was similar to that showed by silica fume [81].

Moraes et al. [1] prepared bamboo leaves' ash with a maximum burning temperature of 738°C after 15 min of autocombustion; then, the ashes sieved (300 μm) to eliminate unburned materials and then milled for 50 min. XRD with an instrument Shimadzu XRD-6000 was used to determine the material mineralogy. The laboratory experiment present in Figure 4 shows that the ash presented a deviation in the baseline, which is best seen in the magnification located in the top right corner of the figure, which means that the BLA was amorphous in nature. However, the material also presents peaks corresponding to quartz, and the presence of this mineral is probably due to contamination of the material by soil since the leaves were collected from the ground. Based on their observations made by FESEM (ZEISS ULTRA 55) method before and after milling, the particle morphology of the BLA has median particle diameter (D_{50}) which is 20.0 μm, irregular, porous, and rough form. Table 8 shows the mineralogical and morphological characteristics of bamboo leaves' ashes according the abovementioned researchers.

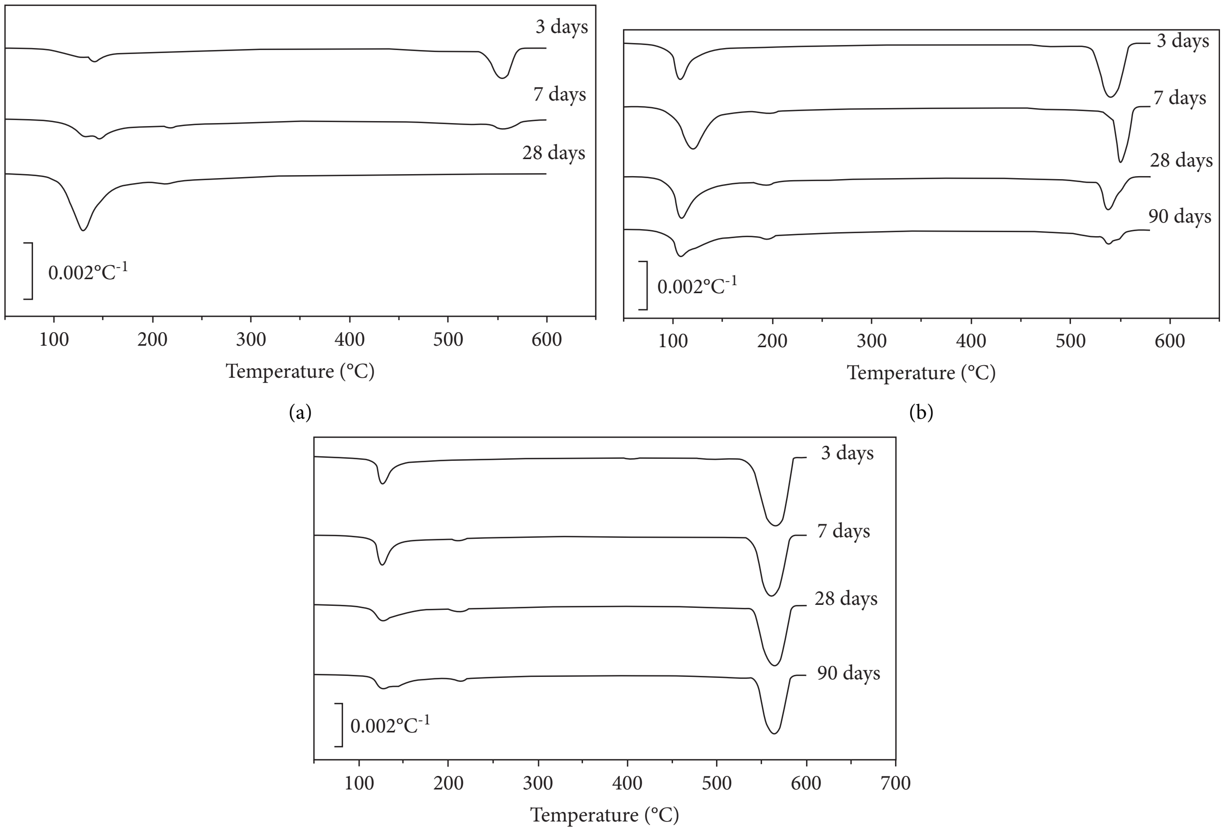
Pozzolanic materials are silicates or aluminum silicates, which for themselves possess little or no hydrates, but finely divided, and in the presence of water can react with calcium hydroxide at ambient temperature to form compounds having cementitious properties [82]. There are different experimental methodologies which have been developed to carry out a qualitative or quantitative determinations of pozzolanic activities [83–85]. Frías et al. [23] made investigations on the pozzolanic behavior of bamboo leaves' ash with accelerated chemical method consisted of putting the BLA (1 g) in a lime-saturated solution (75 ml) at 40°C for 1, 7, 28, 90, and 360 days. They evaluate the pozzolanic activity of the BLA by the determination of fixed lime percentages with respect to the initial total $Ca(OH)_2$ content (17.68 mmol/l) up to 90 days of reaction. Based on the laboratory result, it showed that BLA fixed 50% of the lime content in the solution passing 90% at 3 days in 6 h of reactions. It was observed that BLA has a very high reactivity according to the values of fixed lime. They carried out thermogravimetric analysis (TG/DTG) in BLA/$Ca(OH)_2$ to conduct the weight loss of calcium hydroxide with change in temperature. It was observed that there was a weight loss of $Ca(OH)_2$ between 100°C and 300°C due to the pozzolanic reaction silicates, aluminates, and aluminum silicate hydrates.

Investigations were made by Villar-Cociña et al. [25, 26] and Rodier et al. [24] with electrical conductivity method by 100 ml to 250 ml of saturated $Ca(OH)_2$ solution mixed with 2.10 to 5.25 g of BLA and magnetically stirred at 40°C. They observed that there was a decrease in electrical conductivity of the BLA/$Ca(OH)_2$, and the availability minerals in BLA shows higher pozzolanic activity. Thermogravimetry analysis (TGA) result examined that the content of calcium hydroxide had decreased by 32% content [24].

Four different methods were used to characterize the pozzolanic reactivity behavior of bamboo leaves' ash by Moraes et al. [1]. The methods were electroconductivity and pH (in aqueous CH/BLA suspensions) [86], Frattini analysis (OPC substitution with BLA (by mass) [87], FTIR (CH/BLA pastes with different proportions and curing ages at 25°C), and TGA and FESEM (CH : BLA and OPC/BLA pastes) [88]. According to the electro conductivity and pH result, for all samples, it was evaluated that the consumption of calcium hydrate increased with increase in temperature. The Frattini

Table 8: Mineralogical and morphological behavior of bamboo leaves' ashes.

S. no	Authors	Morphology	Minerology	Surface texture
1	Frías et al. [23]	Amorphous	Calcite, cristobalite, calcium sulphate	Irregular and very small dimensions in size
2	Rodier et al. [24]	Amorphous	Quartz, Ca $(OH)_2$, Calcite, alite, and C-S-H	
3	Villar-Cociña et al. [25]	Not defined	Crystalline minerals not detected	Grey, fine, and D_{50} of 58.1 μm, regular, porous, rough, sponge-like morphology and smooth surfaces on the top
4	Moraes et al. [1]	Amorphous	Silica, quartz, cristobalite, calcium sulphate	D_{50} of 58.1 μm irregular, porous, rough form
5	Villar-Cociña et al. [26]	Amorphous	Quartz, calcite, and cristobalite	Porous, rough and sponge-like morphology



(a)

(b)

(c)

Figure 5: DTG curves for pastes of CH/BLA ratio of (a) 3 : 7, (b) 5 : 5, and (c) 7 : 3 [1].

test curve showed that except 5% replacement, all the samples indicated the increase in the replacement percentage decreases the concentration of the ions, which indicates more consumption of the ions, and there was high pozzolanic reactivity for the ash. Based on the FTIR laboratory results, the consumptions of 99 $Ca(OH)_2$ completely disappeared for pastes with 3 : 7 proportion and decreased with curing time for samples with 5 : 5 and 7 : 3 proportions. Regarding TGA test which was conducted by derivatives thermogravimetric (DTG) curves, for the first 3 to 7 days, the curve shows CH consumed higher CH : BLA ratio of 3 : 7 and completely consumed from 7 to 28 days at near 550°C. For early curing age, the 3 : 7 proportions of the hydrated product increased at temperatures near 120°C–130°C, and the dehydration of C-S-H gel was started. For 120°C–150°C temperature range, after 7 days, the gels spread to the hydration of C-S-H, C-A-S-H, and C-A-H gels. The whole DTG curve (CH/BLA paste) and SEM micrographs of CSH gel for BLA calcined at 500°C result are presented in Figure 5 and Figure 6, respectively, for all samples.

From DTG finding (Figure 5), the amount of CH significantly declines when curing ages increase from 3 to 7 days for pastes with a CH : BLA ratio of 3 : 7; this is witnessed as 550°C peak decreasing significantly until its complete consumption from 7 to 28 days. On contrary, peaks associated with hydration products for a CH : BLA ratio of 3 : 7

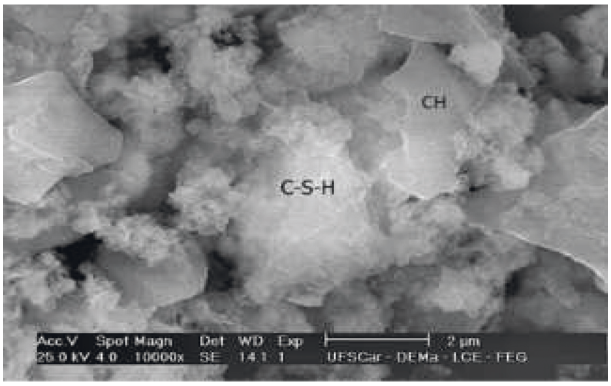


Figure 6: SEM of CSH gel for BLA calcined at 500°C [26].

increased with curing age; for early ages, the peaks were traced about 120–130°C, which is ascribed to the dehydration of the C-S-H gel. After 7 days, the C-S-H gels were located at 120–250°C temperature range, which is apparently distinguished as the dehydration of C-S-H, C-A-S-H, and C-A-H gels [89]. The DTG curves for pastes with a CH : BLA ratio of 5 : 5 revealed that the consumption of CH was not completed as peaks about 550°C remained; nevertheless, the intensity of the peak declined with increasing curing age. The formation of hydrated calcium silicates and calcium aluminates was also traced on the DTG graph. At early curing ages, the peaks are also intense near the temperatures related with the dehydration of hydration products. After 28 days, the gels are reordered, and dehydration peaks exist with a range of 120–250°C. The pastes with a proportion of 7 : 3 showed sharp peaks near 550°C for all curing ages tested, and this happens because the of the large content of CH compared to BLA.

The SEM observation (Figure 6) shows the formation of C-S-H gels in all samples, rough zones having a sponge-like morphology. The laboratory investigations examined by FESEM with an OPC/BLA ratio of 100/0 and 85/15 at 28 days of curing age showed that ettringite (AFt) and C-S-H hydration products have been formed for all samples at peak temperatures between 120°C and 150°C. Furthermore, they performed an additional study to identify the influence of the addition of BLA on the total porosity distributions on the paste samples with mercury intrusion porosimetry (MIP), and 20% OPC replacement showed lowest total porosity. Generally, according to the laboratory results of the above studies conducted to characterize the pozzolanic behavior of bamboo leaves ashes, it can be said that BLA has higher reactive pozzolans.

Parallel to the chemical, mineralogical, morphological, and pozzolanic characteristics of bamboo leaves' ashes, Savastano et al. [23] examined the volume stability behavior of BLA with the volume stability test method in order to estimate the potential risk of delayed expansion due to hydration of free calcium oxide (CaO) and magnesium oxide (MgO) in the form of periclase. They carried out the test according to EN 196-3 and found that BLA blended cements had stable volume similar to the control OPC paste which implies that there were not significant amounts of expansive compounds (quicklime and periclase) in BLA.

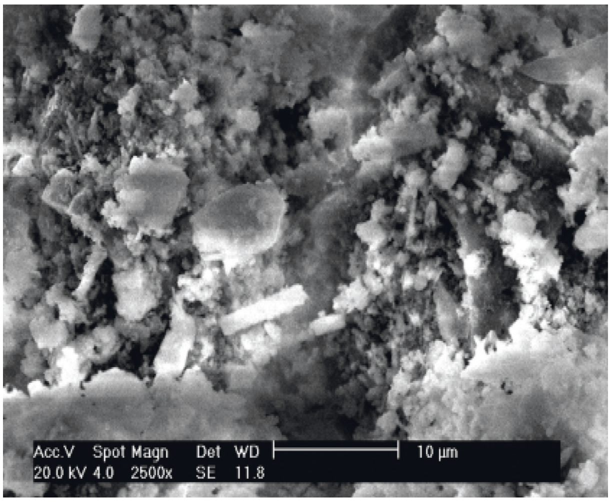


Figure 7: SEM micrograph of BNLA powder [36].

According to Kanning et al. [36], the mineralogical test result of X-ray diffraction (XRD) verified that banana leaves' ashes (BNLA) have an amorphous silica phase of about 83%, and the remaining crystalline phases were identified as calcite ($CaCO_3$), quartz (SiO_2), rutile (TiO_2), and magnesium carbonate ($MgCO_3$). They found that the surface area and specific mass of BNLA was approximately 14,000 cm^2/g and 2.440 g/cm^3, respectively. The XRD test made by Kanning et al. [32] supports the mineralogical behavior of BNLA. Based on the scanning electron microscope (SEM) test result conducted shown in Figure 7, it was observed that BNLA has a median size ranging from 1 μm to 10 μm diameter, angle faces, and less pores particles. They carried out pozzolanic activity index (API) with modified Chapelle's method which showed (422 ± 28) mg of calcium hydroxide fixed, and the result confirms BNLA as a pozzolanic material. Madhu and Eswanth [3] observed that, for BLA 10% replacement level, as age increases, the microstructure of the concrete mixes becomes dense due to the pozzolanic action of WA. It is well known that, the calcium-silica-hydrate (C-S-H) was a major component that influences both microlevel and mechanical properties of concrete. In addition, the physical properties of BNLA were identified as grey in color, specific gravity of 2.04, which is less than ordinary cement (3.14) and 5% of fineness modulus [3].

Memon et al. [44] identified the material characterization of corn cob ashes (CCA) with SEM and XRD. They found CCA samples were well-graded, free from organic impurities, amorphous in nature, and had finer portion and porous morphology due to the presence of micropores, perforations, and tubules. The macro- and micromorphology of corncob and corncob ash is shown in Figures 8 and 9, respectively. The figures illustrate that corncob consists of three layers, i.e., chaff, woody ring, and pith. The chaff/beeswing (Figure 8(b)) is the outermost layer, which is similar to beeswing and forms the honeycomb arrangement. These three portions of corncob are highly absorbent, in particular, pith and chaff are more absorbent than the woody ring portion [90]. The authors also identified that the CCA

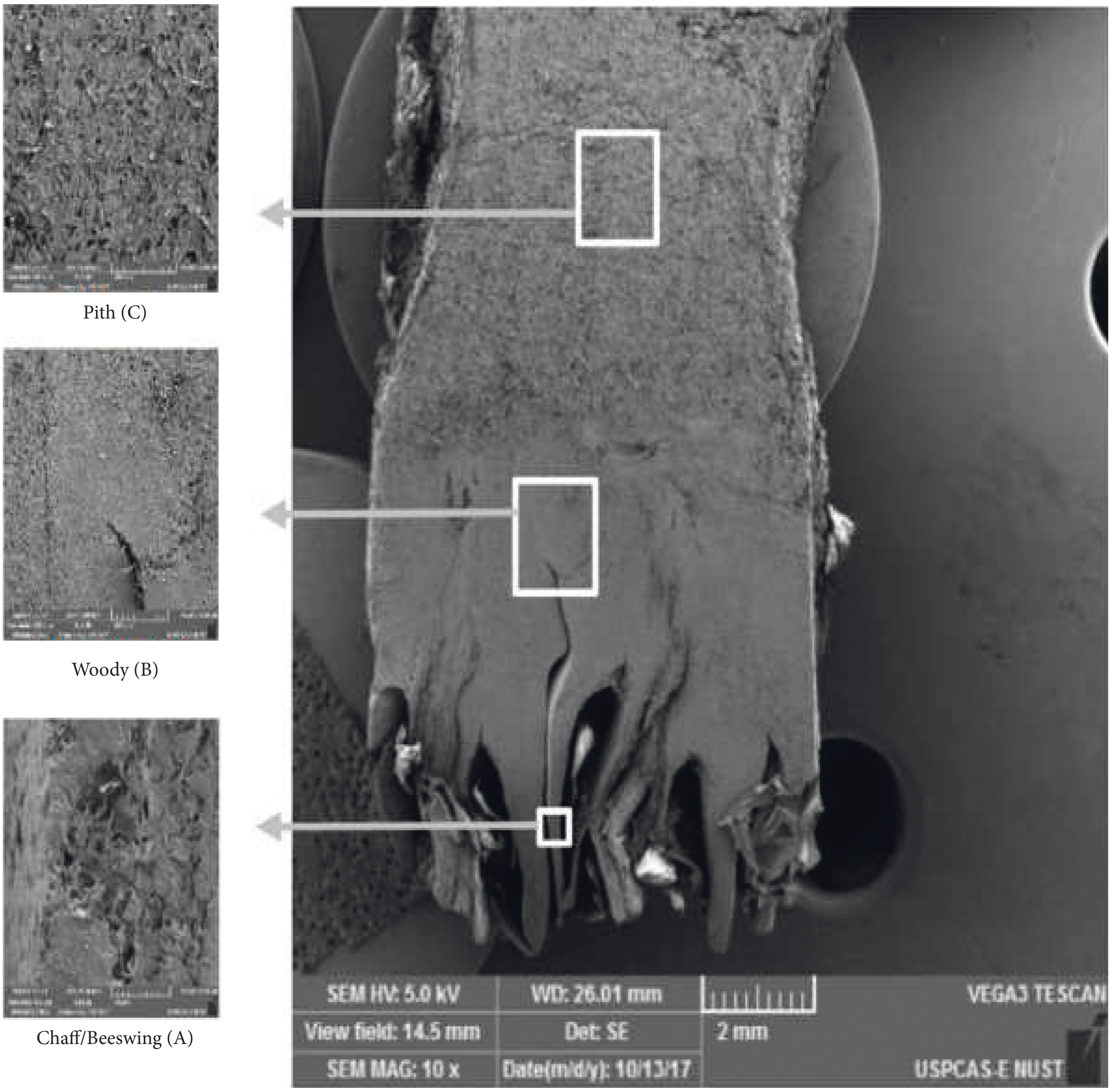


Figure 8: SEM micromorphology of corncob leaf ashes [44].

particles contain long, extremely porous, and perforated tubules. Further result indicated that CCA had a size of 0.5 μm micropores and 10 μm perforations. The result of scanning electron microscopy (SEM) indicates agglomeration of particles with an approximate size of up to 10 μm, and the SEM shows the particles like the shape of bacteria. The XRD crystallographic pattern revealed that CCA was composed of quartz and stishovite at 2Q values of 28.240 ($d = 3.157$ A) and 30.730 ($d = 2.907$ A), respectively.

The laboratory result conducted by Buari et al. [51] with scanning electron microscopy (SEM) and X–ray diffraction (XRD) to examine the mineralogical and morphological behavior revealed that GNA had amorphous nature, irregular surface with visible pores, spongy texture, and crystalline silica. The physical property showed that the specific gravity of GNA was between 2.12 and 2.23 and grey in color [50–52]. It also had a particle median size of 11.42 μm, specific surface area of 21.89 m^2/g, and less fineness modulus properties than that of cement [50, 51]. Usman et al. [50] performed Fourier-transform infrared spectroscopy (FTIR) which analyses the microstructure properties of concrete samples made with 100% OPC and blended 10% GNA. They also investigated at 3642 cm^{-1}; $Ca(OH)_2$ was present in both samples with the appearance of the OH-stretching band. It can be also observed that the Si-O stretching band at 954 cm^{-1} confirmed the formation of C-S-H gels in the samples. Calcite was found with the C-O stretching band at 875 cm^{-1} and bending at 1424 cm^{-1}. But, compared to the reference mix, the blended 10% GNA concrete sample has obtained higher CSH and less Ca $OH)_2$. These high pozzolanic reaction between cement paste and GNA will attributed to the improvement in the compressive strength of concrete.

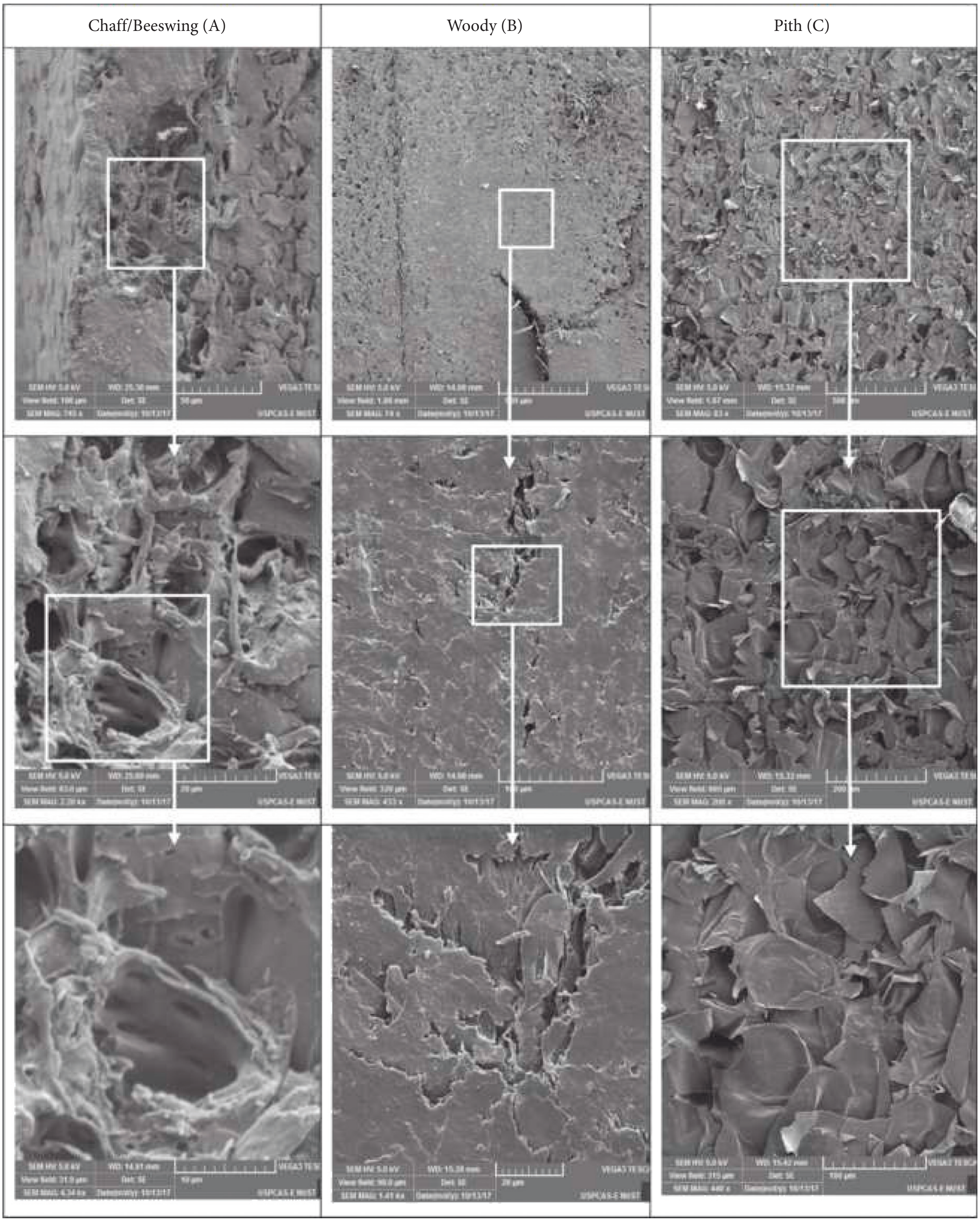


Figure 9: SEM macromorphology of corncob at different magnification [44].

Various metal ions in the rice husk and unburned carbon influence the purity and color of the husk. The X-ray diffraction (XRD) and scanning electron microscopy (SEM) tests conducted by Salas et al. [62], Abiodun and Jimoh [61], Raheem and Kareem [58], Antiohos et al. [57], and Khan et al. [56] had an amorphous nature and basically composed of silica, cristobalite, and some limited tridymite. Commonly, the specific gravity of RHA is lower than that of ordinary Portland cement (3.14). It had a specific gravity between 1.95 and 2.36 [56, 60–62] and a surface area about 24,000 m^2/kg [62]. Generally, the morphological, mineralogical, and physical properties of RHA are summarized in Table 9. The XRD pattern of rapid cooled RHA at 2 theta per degree is shown in Figure 10. The figure revealed a hump

Table 9: Morphological, mineralogical, and physical characteristics of RHA.

Authors	Morphology	Mineral	Specific gravity	Particle size D_{50} (μm)	Color	Surface texture
Khan et al. [56]	Amorphous	Silica	2.1			✓ Particles with micropores ✓ Irregular shape
Antiohos et al. [57]	Amorphous	✓ Mainly silica and cristobalite ✓ Limited tridymite		70.46		✓ Interconnected porous network ✓ Coarse with large porosity ✓ Teeth-like outer shape
Raheem and Kareem [58]	Amorphous	Silica				
Krishna et al. [60]		Silica	1.95			
Abiodun and Jimoh [61]	Amorphous	Silica	2.36	45	Grey	Fine
Salas et al. [62]	Amorphous	Silica	2.16	19	White and pink	

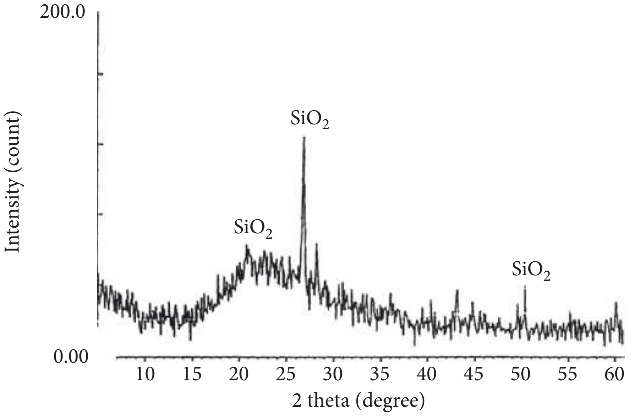
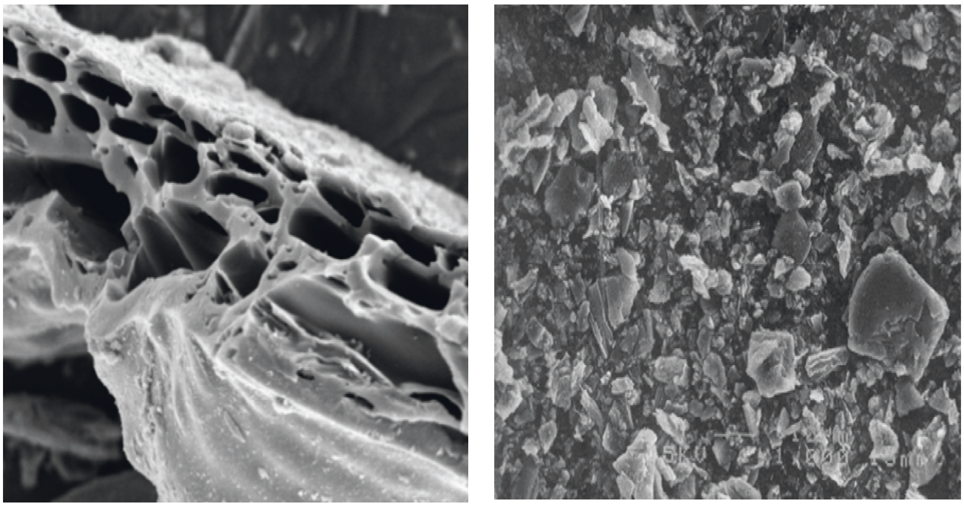


Figure 10: XRD pattern of rapid cooled RHA [56]. (a) [57]. (b) [56].



(a)

(b)

Figure 11: SEM image of RHA: (a) Greek and (b) Pakistan.

which represents its amorphous nature, and the peaks of SiO_2 showed its crystalline property. This literally showed that the RHA has been found in both in amorphous and crystalline nature. The major peak showing the crystalline SiO_2 nature of RHA is traced at 2-theta of 26.64. According to the report made by Tayeh et al. [12], Agwa et al. [14], and Tayeh et al. [17], the burning rice husks results in ash with high silica content. When the burning process is carried out properly, in a controlled atmosphere, the silica in RHA is amorphous, making it a proper cement-replacement material due to its high pozzolanic activity. The SEM micrographs image of Greek's (a) and Pakistan's (b) rice husk ash is shown in Figure 11. The morphology RHAs (Figure 11(a)) exhibit many voids of different sizes which leads to an interconnected spongy network. Likewise, the RHA ashes display a morphology similar to rolling hills, while areas of heterogeneous morphology were also identified. This structure is most likely created as the result of the burning process of the original husk in which the initial coverings retain their shape and give a teeth-like outer surface [91]. The figure also exhibited that the RHA powder consisted of irregular shaped particles with micropores which consequently could significantly affect the properties of the concrete. The porous morphology could arise from the burning out of the organic component in the RHA [92].

Quedou et al. [66] conducted a laboratory-based test with X-ray diffraction (XRD) in order to analyze the physical properties of SCBA. Due to the absorption of silicic acid from soil and deposit in the plant, mineralogical SCBA is amorphous state in nature. They also observed that SCBA had high porous surface and slow pozzolanic reaction with other cementitious materials. Similar test was done by Ganesan et al. [78], and they visualized that SCBA has an amorphous silica structure with a wide scattering peak (hump) centered at about 22° 2θ; Cu KY radiation and small quantities of crystal-phases as quartz and cristobalite are also present (Figure 12). It was also found that SCBA are nearly four times finer than that of OPC with a mean grain size of 5.4 μm and are more uniform in their distribution. They also visualized that SCBA has a compacted bulk density of 0.59 g/cm^3, specific gravity of 1.85, and the specific surface is 943 m^2/kg which is three times higher than OPC (326 m^2/kg). Villar-Cociña et al. [93] suggested that SCBA shows good pozzolanic properties of the sugarcane wastes between 800 and 1000°C (1472 and 1832°F) and no influence of the calcining temperature on the pozzolanic activity for SCBA. According to the XRD analyses made by Abd Elhameed Hussein et al. [79]; the SCBA indicates amorphous silica formation with traces of low quartz. They examined SCBA has more glassy texture and its particle size is much finer than the cement particle. Mangi et al. [80] observed SCBA has a substantial amount of silica particles, pores, and fibrous surface and spherical and prismatic shape. Figure 13 designates that SCBA crystals are smooth in surface and prismatic in shape [95], and similar findings were found in [94, 96, 97].

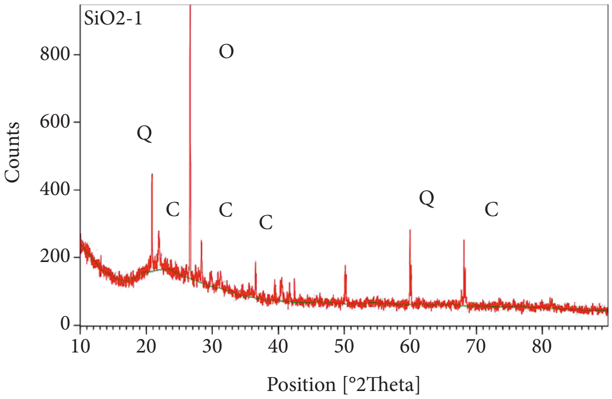


Figure 12: X-ray diffraction pattern of SCBA [78].

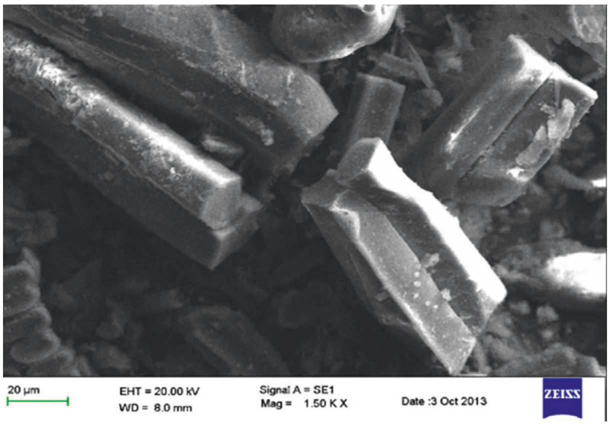


Figure 13: SEM structure of SCBA [94].

2.2. Effects on Fresh Properties of Mortar and Concrete. The rheological properties of bamboo leaves' ash (BLA) blended cement mortar behavior was conducted by Frías et al. [23] with the additions of BLA 10% and 20% into OPC with a sand to binder ratio of 3 : 1 and 0.50 ratio of water/binder. The result showed that the normal consistency of the blended cement pastes was improved with the addition of BLA, and the demand for water content was increased by 19% and 46% to the additions of 10% and 20% BLA, respectively, compared to 100% OPC. They observed that due to the presence of minimum contents of ZnO and PbO in BLA and oxides, the setting time (initial and final) did not modify and delayed slightly with 20% of BLA. Silica fume, metakaolin, sugarcane bagasse, rice husk ash, paper sludge, and ceramic residues had similar pozzolanic behavior with BLA [81, 98, 99]. Abebaw et al. [21] replaced cement with BLA at a percentage of 5%, 10%, 15%, and 20% at a constant water-cement ratio of 0.49. They found that due to the fineness of BLA and large specific surface area, the slump values go down as the replacement level BLA increases, up to 10% replacement level, the slump is still in the estimated range of 25 mm to 50 mm.

The investigations made for banana leaves' ash (BNLA) based mortar showed that the amount of air-entrained content was slightly decreased by the addition of BLA when compared to the normal one [36]. They examined the effect of using BNLA in the properties of mortars and concrete. They replaced cement by BNLA about 5%, 7.5%, and 10% with a water binder ratio of 0.59%, 0.58%, and 0.57%, respectively, for mortar and 10% and 20% with constant 0.5% of W/*c* for concrete. They found that BNLA samples presented smaller deformation than the reference mortar, and it may be needed to spread it on floors and walls, diminishing its productivity. Dhage et al. [37] reported that standard consistency of cement by using normal cement is achieved at

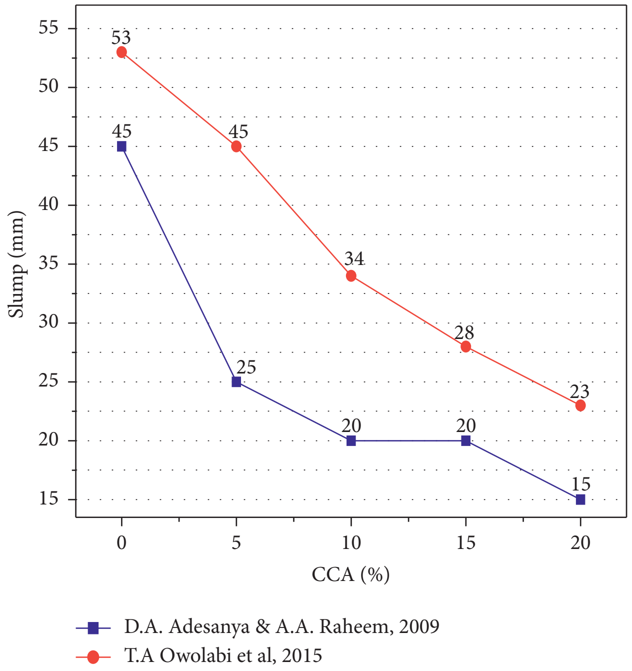


Figure 14: Slump test value for corncob leaves' ashes blended concrete.

32% and 28% by using BNLA. It was also found that the initial and final setting time of cement by using BNLA is reduced from 60 min to 53 min (12%) and from 490 min to 467 min (4.7%), respectively.

Several studies revealed that the addition of corncob ashes (CCA) would lead to reduction in the degree of workability. Adesanya and Raheem [41] and Owolabi et al. [42] conducted the workability of CCA-based concrete by slump test by various percentage replacement, mix ratio, and water-cement ratio. Based on the combined slump test result shown in Figure 14, the workability was drastically decreased with the inclusion of CCA content in concrete, and additional water is required in order to make the concrete workable during the hydration of cement [100–102]; this might be because CCA has larger surface area compared to cement.

One such study was carried out by Buari et al. [51] to investigate the fresh properties of high-performance self-compacting concrete (SCHPC) with a partial replacement of cement by 10%, 20%, 30%, and 40% ground nut ashes (GNA) at 0.37 constant *w/c*. According to the result obtained, the slump value was decreased with increased in GNA content, and it was observed that compared to the control mix, the percentage reductions were 3.2%, 3.7%, 6.8%, and 11% at GNA content of 10%, 20%, 30%, and 40%, respectively. The V-funnel and T500 test output revealed that all mixes have good workability and consistency and it takes lower flow time in molds. It was also found that the segregation value and resistance increased with increase in substitution levels. Usman et al. [50] assessed the water demand, workability, and soundness properties of ground nut ashes (GNA) concrete mix samples by partially replacing cement from 0 to 50% with 10% interval at 0.36 water binder ratio. The test results show that more water is required to maintain the required consistency recommended by ASTM C 618. They suggested that due to the spongy nature of GNA particles which leads to their high surface area, rate of water demand increased with increasing GNA content. The result of the experiments indicated that the need for water for the mix specimens was higher than that of the control by 100% and 146% with GNA content of 30% and 50%, respectively. It was found that GNA retarded both the initial and final setting times of cement paste; however, at all replacement levels, they did not exceed the ASTM standards of the minimum initial setting time (60 mins) and the maximum final setting times (600 mins). The soundness (expansion) test value reported that the soundness of paste has improved and increased with the GNA content. They evaluated that compared to 0% GNA, the expansion blended specimens with 10%, 30%, and 50% GHA were lower by 8%, 28%, and 56%, respectively.

Rice husk ash (RHA) blended cement would be applicable in a place where low rate of heat development is required like in mass concrete. Raheem and Kareem [58] replaced RHA by the weight of ordinary Portland cement with 5%, 7%, 11.25%, 15%, 20.25%, and 25%. The result indicated that compared to the control mix, the initial and final setting increased with the addition of RHA up to 15%. Also, furthermore, they observed that soundness and consistency has improved with increase in RHA percentages. For 15% RHA content, compared to the normal mix, the initial setting time, final setting time, and consistency increased by 151%, 190%, and 21%, respectively. A contradictory result was investigated by Krishna et al. [60]. They used 5%, 10, 15%, and 20% of RHA content to partially replace cement, and both the initial and final setting time decreased with percentages increment of RHA, while the consistency increased slightly. For the same 15% of RHA content, there was a reduction of 47% and 11% in initial and final setting time, respectively, and the consistency increased with 14%. This might be happened due the high porosity of RHA. Table 10 shows the setting time and consistency result comparison of the two studies.

Ganesan et al. [78] evaluated the consistency and setting time of fresh concrete made with 100% OPC and OPC replaced by sugarcane bagasse (SCBA) at percentage levels of 5%, 10%, 15%, 20%, 25%, and 30% and a constant water-cement ratio of 0.53. The result revealed that all the consistency and initial and final setting time were constantly increased with an increment of the SCBA replacement level. It showed that compared to 100% OPC at 30% content of SCBA, the consistency and initial and final setting time improved by 80%, 182%, and 45%, respectively. This indicates that SCAB-based concrete does not require too much water in order to make the concrete more workable. Similar to Ganesan et al. [78], Abd Elhameed Hussein et al. [79] also conducted the workability of concrete for similar replacement of OPC with SCBA. They investigated that the workability of concrete was linearly increased with the increment in the SCBA content. Reference to the normal concrete, the 30% SCBA contained concrete had a slump value of about 215 mm which is 34% better than that of

Table 10: The effects of RHA in workability of concrete.

RHA (%)	Initial setting time (mm)		Final setting time (mm)		Consistency (%)	
	Raheem and Kareem [58]	Krishna et al. [60]	Raheem and Kareem [58]	Krishna et al. [60]	Raheem and Kareem [58]	Krishna et al. [60]
0	175	55	250	141	4	41
5	280	41	425	136	6	44
10	135	32	225	130	6	46
15	440	29	725	125	5	47
20	210	24	293	118	5	51

normal concrete (160 mm). It implies that the inclusion of SCBA level reduces the water demand in concrete for achieving the desired workability. Figure 15 shows the water consistency, and Figure 16 elaborates the examined results of slump value and initial and setting time of fresh concrete. The other observations were investigated by Mangi et al. [80] for a slump of C-20 and C-15 grades of concrete with 5% and 10% SCBA content at different mix ratios. Based on the investigations conducted, the workability was improved by the percentage's replacement level of SCBA for both grades of concretes, and compared to the normal mix, the 10% SCBA mix shows 45% and 28% increment of slump value for C-20 and C-15 grades of concrete, respectively. They also observed the slump value fall in the category of low and medium degree of workability.

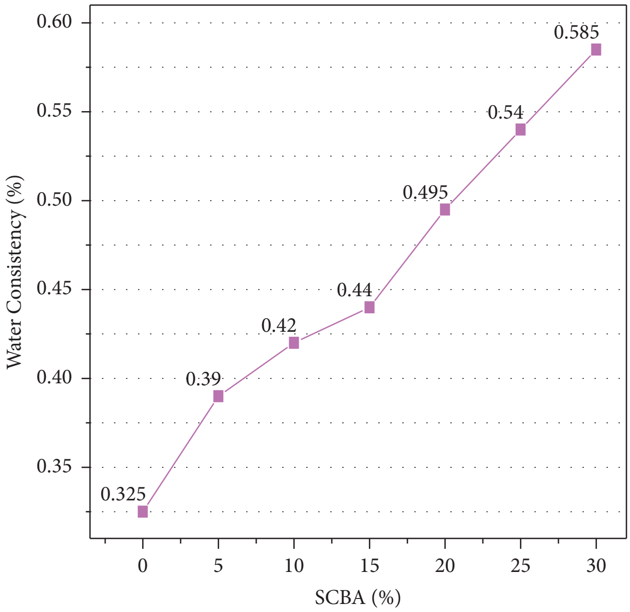


Figure 15: Water consistency of fresh concrete. [79].

2.3. *Effects on Hardening Properties of Concrete and Mortar.*

Frías et al. [23], Rodier et al. [24], and Moraes et al. [1] investigated the compressive strength of mortars by bamboo leaves' ash (BLA) blended with cement pastes with respect to the control one. They prepared the samples with a BLA content of 10% and 20% of BLA [23, 24] and 5%, 10%, 15%, 20%, 25%, and 30% [1] with a constant water binder ratio of 0.50 [23, 24]. According to Frías et al. [23], compared to the control mortar, at 7 and 28 days, the compressive strength of the mortar was reduced by only 1% and 2.8% for 10% and 20% of BLA, respectively, which satisfied the requirements by ASTM C 618-03 (75% strength of gain at 7 and 28 days), and because of the formation of hydrate compounds of C-S-H during the hydration reaction cement and the pozzolanic reaction of BLA [24], it observed 14% increment for 20% of BLA. Moraes et al. [1] evaluated that the mortars with OPC replacement presented very similar compressive strength after 7 curing days; the mortar with 30% BLA presented a strength gain (SG) of 56% at 90 days of curing. The reason behind these outcomes were the reaction between the silica or aluminosilicate and the calcium hydroxide forms additional C-S-H, which fills the capillary pores [24, 103]. Figure 17 shows the summarized the approximate compressive strength of mortars by the partial replacement of OPC with 10% and 20% of BLA based on the researchers' studies. According to the result of Abebaw et al. [21], both dry density and compressive strength of concrete decreased as the percentage of BLA replacement levels increased, which was because of physical properties of BLA; the unit weight is 1,217 kg/m^3 that is lighter than OPC cement of 1,400 kg/m^3. It showed the density was reduced by 1.67 and 2.06 for 15% and 20% of BLA, respectively, compared to the reference mix of OPC. Regarding to the compressive strength, the concrete samples achieved their target mean strength after 28 days when the OPC was replaced by BLA up to 10%, whereas the situation was changed for 15% and 20% of BLA, but they attained the characteristic strength of 25 MPa on the 28th day with 30.47 MPa and 27.88 MPa, respectively.

According to Kanning et al. [36], Figures 18(a) and 18(b) show the compressive and tensile strength of the mortar, respectively. Based on the figures, both compressive and tensile strength increased for 5% and 7.5% content of BNLA through curing ages and decreased with the use of 10% BNLA. However, when compared to the reference sample, there was an improvement in both tensile and compressive strength for all samples. They observed that all mortar samples had ruptured in the substrate, and they classified the mortar as resistance blocks [104]. At 28 days, for the same water-cement ratio, the 10% and 20% BNLA mixtures concrete were observed to have higher mechanical strength than 0% BNLA with 25% and 40%, respectively. These might be due to the result of the lower porosity of the substrate surface penetration of cement slurry particles in to the capillary effect. B [37] did a series of casting involving mix designs for C-30 grades of concrete and *W*/*c* of 0.50. The effect of BNLA on compressive strength, split tensile

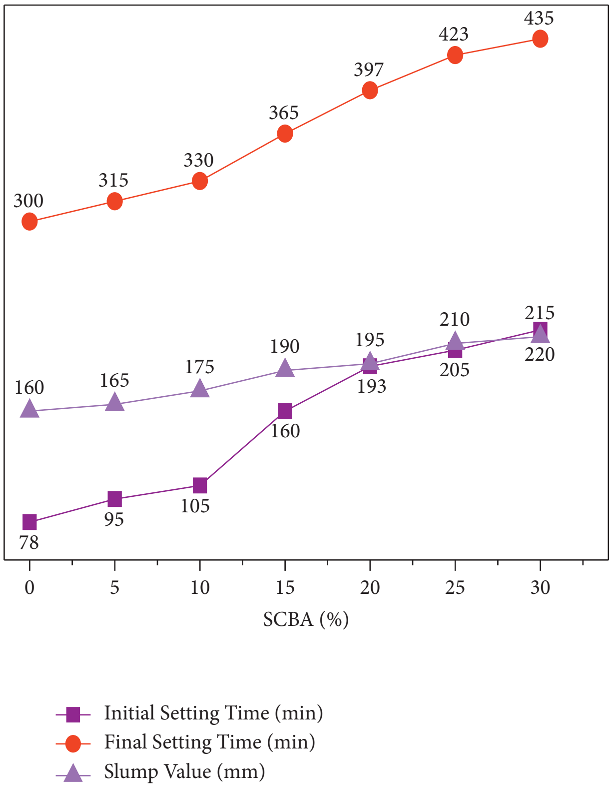


Figure 16: Slum value, initial setting time, and final setting time of fresh concrete [79].

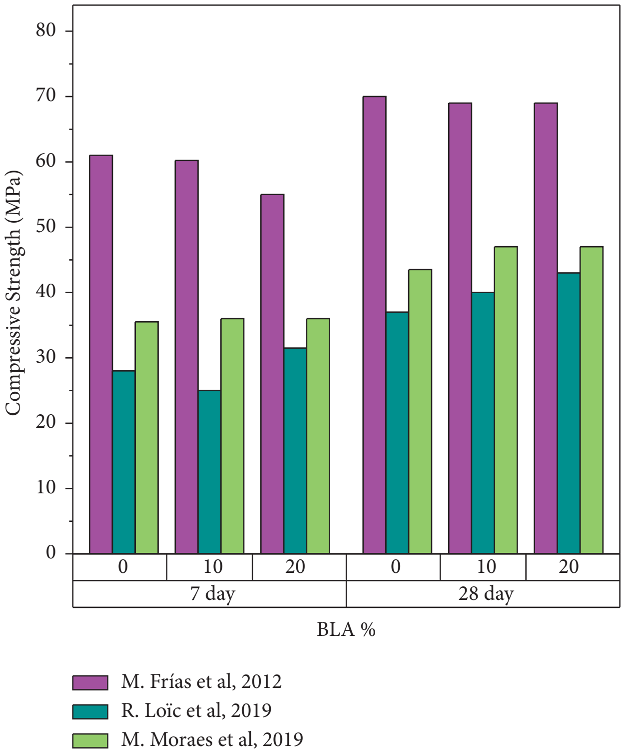


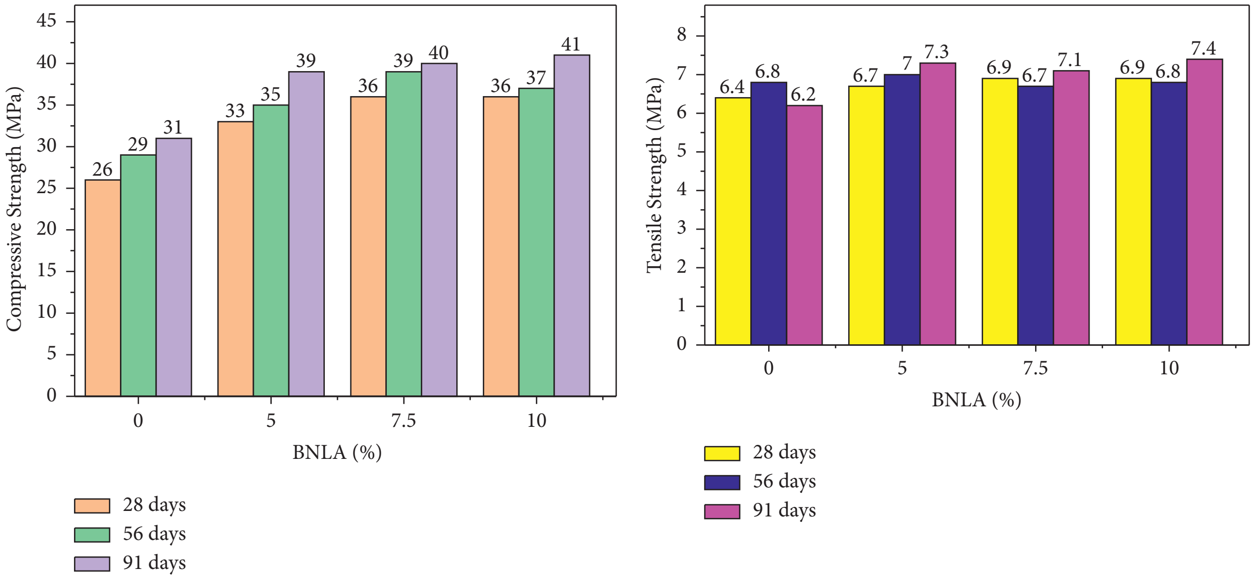
Figure 17: Compressive strength of binary mortars at 7 and 28 days.

strength, and flexural strength of concrete for 20%, 30%, 40%, and 50% cement replacement at 28 days and 56 days curing ages is given Table 11. The compressive strength results showed a constant decrease in the increment of BNLA percentages and curing periods; the reason might be both fractured and cut surfaces morphological and bonding within the banana [105]. Nevertheless, it was observed improved results from 28 days to 56 days curing ages with 71%, 120%, 92%, and 87% for BNLA content of 20%, 30%, 40%, and 50%, respectively. According to the figure, it was observed that there was a better split tensile strength at 56 days with 30% replacement, but when increased in replacement ratio, then split tensile strength decreased. The table also indicates 30% BNLA replacement gave an optimum flexural strength at both 28 days and 56 days curing periods; however, it has observed improvements with curing ages.

Based on the various tests conducted by Singh et al. [43], the compressive strength of concrete mixtures made with corncob ashes (CCA) pozzolanic cementitious material decreased with increase in temperature beyond the standard room temperature (20°C). They demonstrate laboratory tests to compressive strength for concrete at different elevated temperature (150°C, 300°C, 450°C, and 600°C) with a CCA content of 5%, 10%, 15%, and 20% to replace cement partially at 0.45 water binder ratio. Based on Figure 19, compared to the normal temperature, the strength of CCA concrete is decreasing for temperatures higher than 300°C. It was visualized that the maximum compressive strength was achieved at a temperature of 300°C for all mixes with the optimum content of CCA is 10%; even though reductions were observed with the inclusion of CCA percentages. They suggested the reduction is attributed to the fact that chemically bound water starts to disintegrate and evaporate at this stage.

Relative to the control mix, the compressive strength of CCA-blended concrete gets lower at early ages; however, it improves significantly. Owolabi et al. [42] and Desai [45] evaluated the potentials of partial replacement of cement for concrete by CCA at 5%, 10%, 15%, and 20% and 10%, 20%, and 30% with a *w/c* of 0.65 and 0.55, respectively, at different curing periods. Compared to the control mix, 20% content of CCA, the compressive strength of the concrete specimens decreased to a maximum of 40.43% and 45.80% [42] and 20.10% and 9.11% [45] at 7 d and 28 d curing ages, respectively, and supported by Adesanya and Raheem [40] and Bheel and Adesina [46].

Based on different researchers' results, it was examined that, with the curing ages of corncob-based concrete, the split tensile and flexural strength of all mixtures was increased. According to Desai [45]; the addition and increment of corncob ashes (CCA) in concrete would result in reduction of the tensile strength. They observed that, at 7 days and 28 days concrete ages for 20% CCA, the split tensile strength was reduced by 20% and 9% from the control mix, respectively. For the same CCA content, they also investigated the flexural strength slightly decreased relative to the control mix from 6.59 to 6.44 N/mm^2 (2.28%) at the ages of 90 days, and a better strength was gained with 10% CCA. The



(a) (b)

Figure 18: Effect of BNLA on mortar strength. (a) Compressive and (b) tensile [36].

Table 11: The effects of banana leaves' ashes on compressive, tensile, and compressive strength of concrete [37].

Samples	Compressive strength		Split tensile strength		Flexural strength	
	28 days	56 days	28 days	56 days	28 days	56 days
20% BLA	20.41	34.91	1.16	1.64	2.14	5.54
30% BLA	13.64	30.11	1.27	1.95	2.88	6.36
40% BLA	10.24	19.72	1.02	1.43	2.61	6.31
50% BLA	8.22	15.38	1.01	1.35	2.54	5.46

study showed that the optimum percentages of CCA that should be used in order to obtain maximum split tensile and flexural strength was 10%. Similar earlier research was done by Adesanya and Raheem [40], and they achieved that tensile strength increased with further curing period. The increase in strength with age can be attributed to the continuous hydration reaction of PC and the pozzolanic reaction of the BCM with time which results in more product formation and densification of the microstructure [40].

According to Buari et al. [51], except 10% replacement of ground nut ashes (GNA), the compressive strength of all specimens of high-strength self-compacting concrete decreased with increase in percentage replacement of cement. However, it was examined that, with the addition of 5% of $MgSO_4$, $CaSO_4$, and H_2SO_4 independently in the concrete mix, the strength of all samples was greatly improved from 7 to 28 days of curing period. The laboratory test conducted by Nwofor and Sule [52] and Usman [50] visualized that relative to control mix, the compressive strength highly decreased when the GNA replacement levels increased, and it improved with later stages of curing period. The result showed that the strength increased by 170% and 270% for 10% and 40% GNA content, respectively, from early ages to later 28 days of curing period.

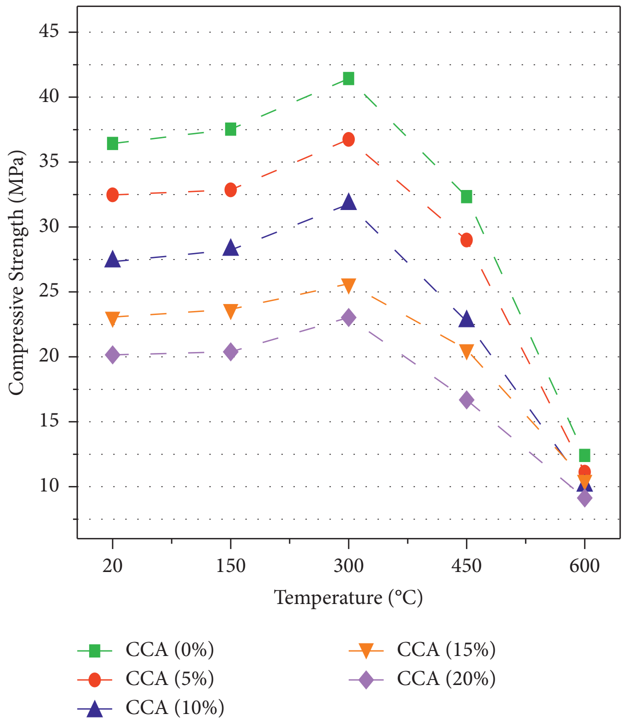


Figure 19: Compressive strength of concrete with CCA at varying elevated temperatures [43].

Jamil et al. [106] analyzed the compressive strength of rice husk ash (RHA) blended mortars and concrete with 0 to 35% with 5% intervals at the curing ages of 28 days. The examined result showed that the 28-day compressive strengths of mortar were higher than the control mix to 25% inclusion of RHA content, and the 35% RHA replacement had similar value with the control mix one. They also visualized that a better compressive strength of

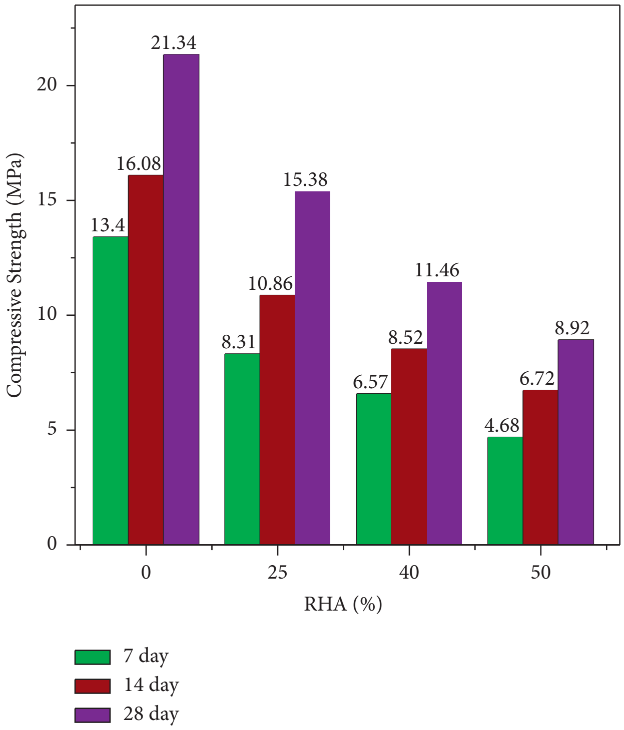


Figure 20: Compressive strength of concrete without SP [56].

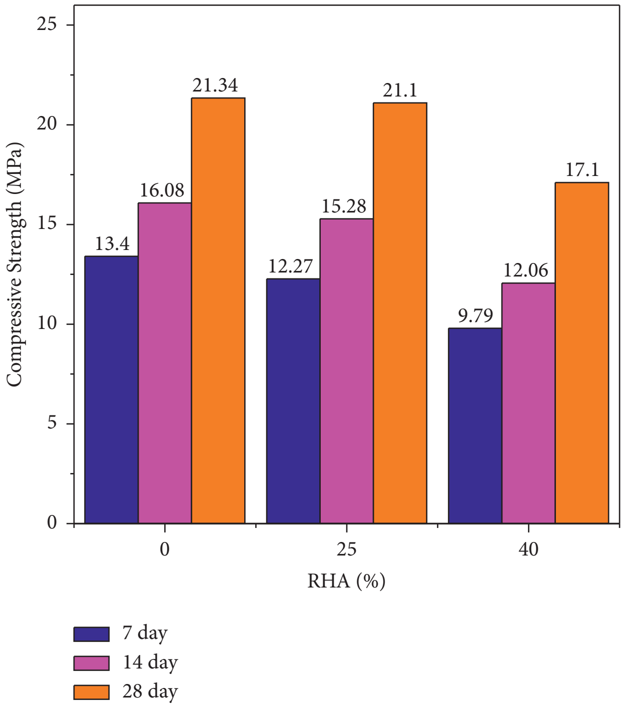


Figure 21: Compressive strength of concrete with SP [56].

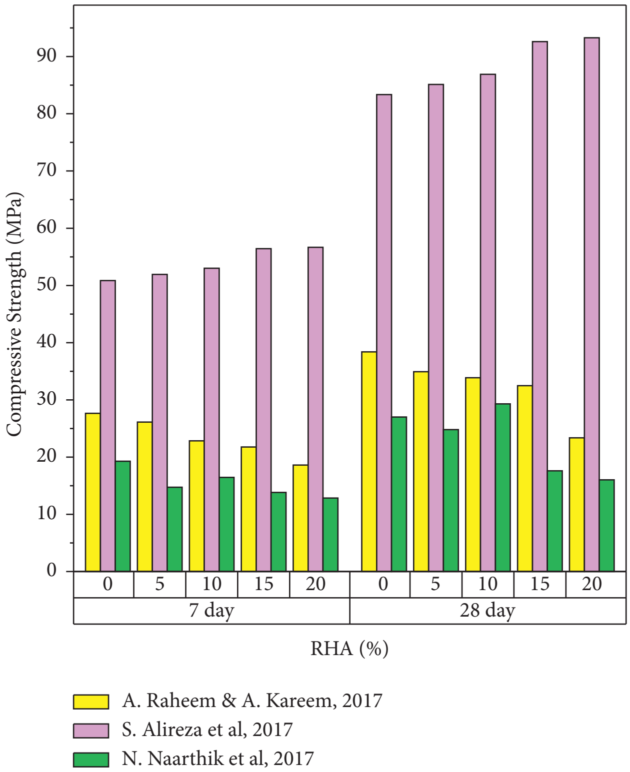


Figure 22: Compressive strength of concrete containing RHA.

concrete samples had been achieved when ordinary Portland cement is replaced by 30% RHA; the result was in agreement with that of [107]. The maximum compressive strength observed for RHA percentage replacement of 15% and 20% for mortar and concrete, respectively; Zareei et al. [59] found the same result and optimum level for concrete compressive strength. This might be the heat evolution in the RHA increases the hydration of cement [108]. Similar research was done by Khan et al. [56]. They tested and compared the compressive strength of partially cement replaced concrete by 25%, 40%, and 50% of rapid RHA without superplasticizer and 25% and 40% without superplasticizer (SP) at ages of 7, 14 and 28 days. It was shown in Figures 20 and 21, for all mixes, the compressive strengths of concrete with SP are greater than concrete without SP. According to the result obtained, for both concrete mixes, relative to the normal mix, the compressive strength decreased when the RHA content increases and increased with later curing period.

According to Raheem and Kareem [58] and Krishna et al. [60], the percentage replacement of cement with RHA would result in the reduction of compressive strength of concrete. In contrast, Zareei et al. [59] observed that the strength highly improved with 25% addition of RHA. They suggested 20% RHA content was the optimum level and compared the control mix (0% RHA); the 28-day compressive strength increased from 83.36 MPa to 93.28 MPa which is about 12% increment. The presence of amorphous silica might improve the interface transition area or zone (ITZ), leading to the concrete's more packing density and enhancing the compressive strength [107, 109–116]. Figure 22 summarizes and compares the approximate 7 and 28 days of compressive strength of concrete conducted by Raheem and Kareem [58]; Krishna et al. [60]; and Zareei et al. [59] at RHA percentages of 0%, 5%, 10%, 15%, and 20%.

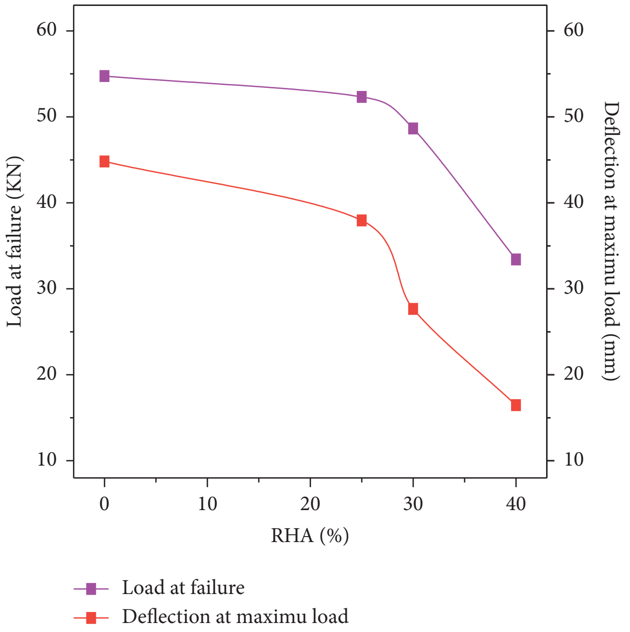


Figure 23: Flexural strength of concrete beams containing RHA [56].

Khan et al. [56] carried out a series test flexural strength by load at failure and deflection at failure with pure OPC concrete beams and concrete containing 0%, 25%, 30%, and 40% of RHA as a replacement of OPC. According to the result shown in Figure 23, the load taken by normal concrete beams was greater than the RHA concrete beams at the first crack development and failure. They examined that deflection of concrete beams at mid span decreased with the increase of RHA content and for 25% RHA, the beam performed very well in flexure and its failure load was 32 mm as compared to the 38 mm control mix. Krishna et al. [60] investigated the flexural strength and split tensile strength with RHA contents of 10% and 15% and 5%, 10%, 15%, and 20%. It was found that, at 10% addition of RHA in concrete, compared to the relative 0% RHA, the flexural strength increased from 2.11 N/mm^2 to 2.53 N/mm^2 (19.9%), and at 15% RHA, it reduced by 0.17 N/mm^2 (8.06%). They examined that the split tensile increased with the percentage increase in RHA, and maximum strength was observed at 10% RHA content. They revealed that the reason behind the improvement of the flexural and tensile strength of the concrete is may be due to the strengthening of the interfacial transition zone (ITZ) by the silica content present in RHA and ITZ of the concrete which becomes stronger since the pozzolanic products given by RHA helps in improving the bonding between cement mortar and aggregates. Furthermore, the addition of RHA beyond 10% will lead to reductions in the split tensile strength.

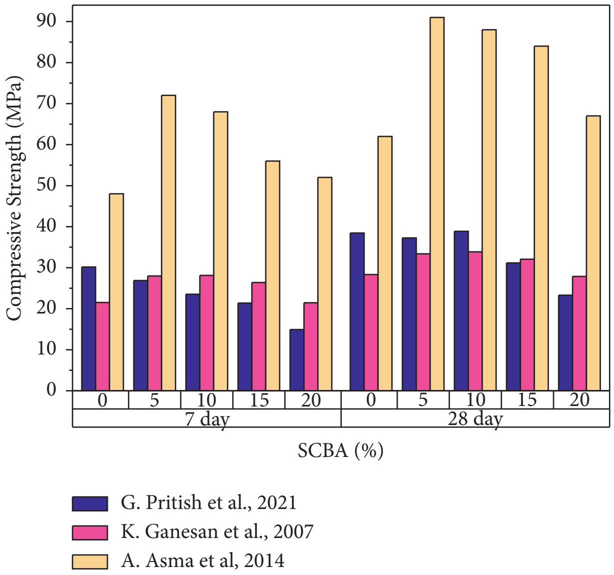


Figure 24: Compressive strength of SCBA-based concrete.

Due to low chemical composition of silicon oxide (SiO_2) content, the compressive and flexural strengths of concrete decreased when the SCBA content is increased [66, 117]. They replaced OPC with 5%, 10%, 15%, and 20% of SCBA content to analyze the effect of SCBA on the properties of concrete having 28-day target compressive strength of 27 MPa. For 20% replacement of SCBA, the test result indicates that the 28-day compressive strength of the concrete cubes recorded 23.28 MPa out of the target 27 Mpa (86%), and compared to the control mix, the flexural strength reduced from approximately 4.75 MPa to 3.70 MPa which is decreased by 22%. Ganesan et al. [78] demonstrated a test for 25 MPa design cube compressive strength of concrete made by OPC replaced with 5% to 30% SCBA at 0.53 *w/c*. They examined that the 28-day compressive strength of all samples achieved a higher value than the target design strength even though reductions observed compared to the normal mix and the optimum replacement level of SCBA was 10%. It was also found that the split tensile strength of the concrete was increased up to 15% of SCBA and further addition of SCBA showed a decrease in strength. Similarly, Hussein et al. [79] demonstrated a laboratory-based investigation at 0.38 *w/c*, and concrete mixes containing 5, 10, 15, and 20% of SCBA achieved higher compressive strength than the reference mix. The highest compressive strength was obtained at 5% SCBA replacement level. Figure 24 shows the compressive strength of concrete mixed with 0%, 5%, 10%, 15%, and 20% SCBA conducted by Quedou et al. [66], Ganesan et al. [78], Abd Elhameed Hussein et al. [79], and Lathamaheswari et al. [118]. Based on the result obtained by Mangi et al. [80], the 28-day compressive strength of both C-15 and C-20 grades of concrete mixes was higher than that of the control mix. They observed that if cement is replaced by 5% SCBA in concrete, compared to the control mixes, the average 28 days compressive strength will be 11.50% and 12% for C-15 and C-20 grades of concrete, respectively, and the maximum compressive strength was attained at 5% SCBA.

2.4. Effects on the Properties of Durability of Concrete. The water absorption capacity of bamboo leaves' ash (BLA) blended cement concrete decreases with 5% addition of BLA

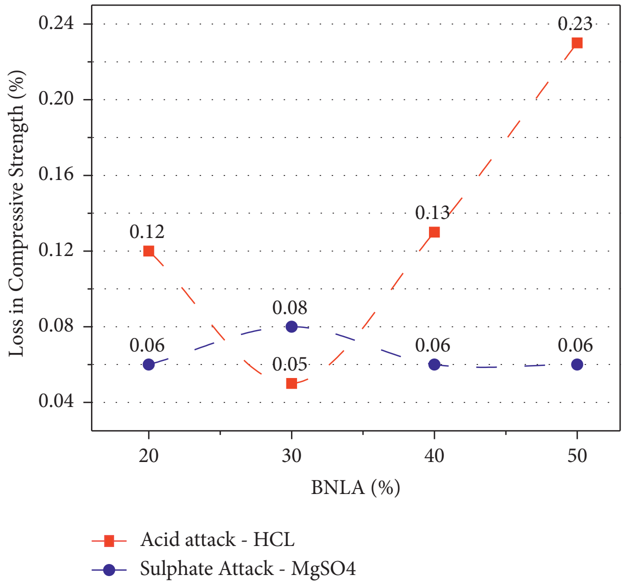


Figure 25: % loss in compressive strength of banana leaves' ashes with HCl and $MgSO_4$. [37].

in concrete [21]. They examined that the water absorption of 10% BLA was higher than the control OPC mix and then starts increasing from 15% to 20%. On 28-day curing period, its percentages range between 2.90% and 3.60% with the least value attained at 5% BLA (2.90%) content, and the greatest value of 3.6% was attained at 20% BLA content.

Madhu Prasad and Eswanth [3] conducted experiments in water absorption, acid and sulphate attack on concrete samples for 10% banana leaves' ash (BNLA). They investigated that absorption after immersion of the samples from water, the volume of the voids is presented by 9.09% and 7.43% with 0% and 10% BNLA content, respectively. It was also observed that, after exposing the 10% BNLA blended concrete mix to acidic calcium salts, the compressive strength was reduced from 44.44 MPa to 38.35 MPa (13.79%). Based on the researchers' analysis, the compounds responsible for sulphate attack on concrete are water-soluble sulphate-containing salts, such as alkali-earth (calcium and magnesium) and alkali (sodium and potassium). They revealed that, as a result of the sulphate compounds in the concrete, 2.39% and 5.06% reductions in weight and compressive strength of concrete were observed at 0% and 10% BNLA. Dhage et al. [37] investigated the durability performance of concrete to acid attack with HCl acid and sulphate attack with $MgSO_4$ by replacing cement with BNLA at 10%, 20%, 30%, and 40%. After 28 days and 56 days of test conducts, Figure 25 indicates that, for HCl, the compressive strength was 0.124%, 0.05%, 0.126%, and 0.228% with the percentage of BNLA. It was also found that the percentage decrease in compressive strength was observed as 0.06%, 0.08%, 0.06%, and 0.06% for $MgSO_4$ with respect to the percentage of BNLA. Finally, they concluded that banana leaves' ashes-based concrete has resistance to acid and sulphate attacks.

Table 12: Water absorption of RHA concrete [59].

RHA content (%)	Saturated water absorption (%)		Percentage reduction from 100 OPC	
	7 days	28 days	7 days (%)	28 days (%)
0	6.03	4.12		
5	5.86	3.95	2.82	4.13
10	5.64	3.70	6.47	10.19
15	5.39	3.46	10.61	16.02
20	5.11	3.23	15.26	21.60
25	4.87	3.05	19.24	25.97

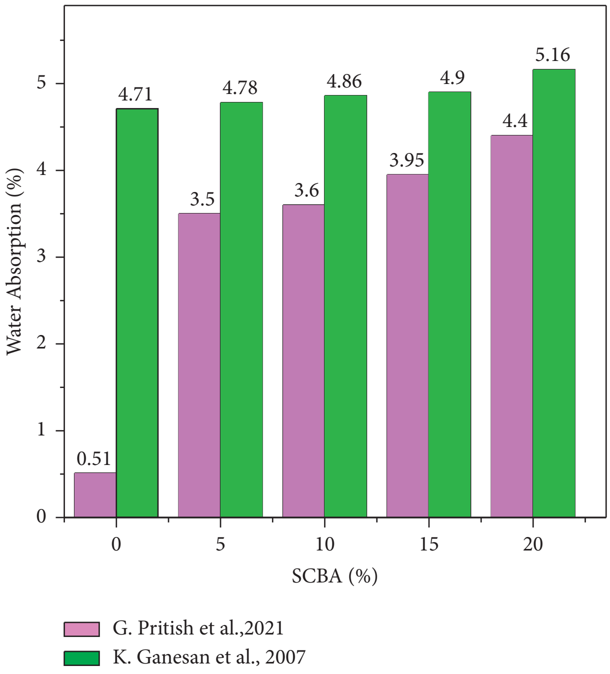


Figure 26: Water absorption of OPC-SCBA concrete.

The water absorption capacity of RHA concrete is lower than that of pure OPC concrete. Zareei et al. [59] did a short-term water absorption capacity of concrete by replacing cement with RHA at 0%, 5% 10%, 15%, 20%, and 25% for 7 days and 28 days of curing ages. They measured the water absorption of concrete mixes after water curing of the specimens for 72 h and oven-dried at 105°C. Compared to the normal mix, for both 7th and 28th days of curing samples, it was found that the saturated water absorption percentages decreased with the inclusion of RHA due to the porosity and pore connectivity of the pozzolans with time [119]. The water absorption capacity of pure OPC and RHA mixed concrete and its reduction with respect to RHA content is given in Table 12. In addition to the water absorption test, they also performed the chloride permeability test for concrete containing different percentages of RHA content. Based on the results, it was assessed that the concrete permeability decreased with increase RHA amount in the concrete; hence, the strength of the concrete would improve. They described that replacement with 25% rice hush ash results in drastic enhancement of the permeability properties of blended concrete compared to that of ordinary concrete, such that it leads to 26% reduction in water permeability and 78% reduction in chloride permeation.

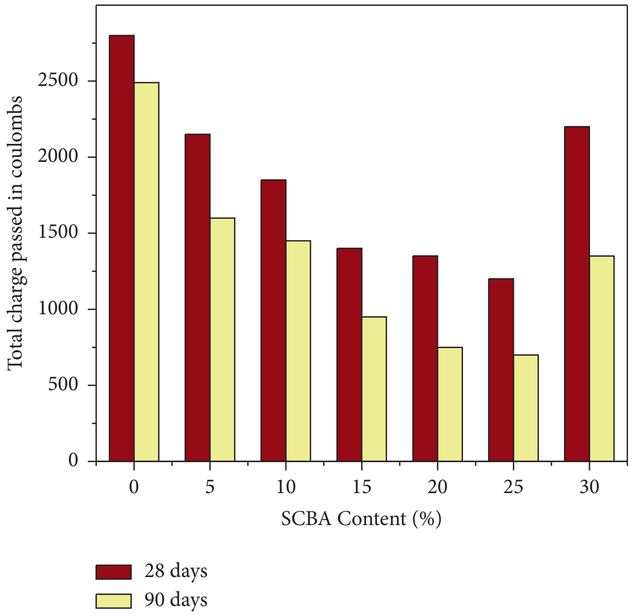


Figure 27: Chloride permeability of SCBA containing concrete [78].

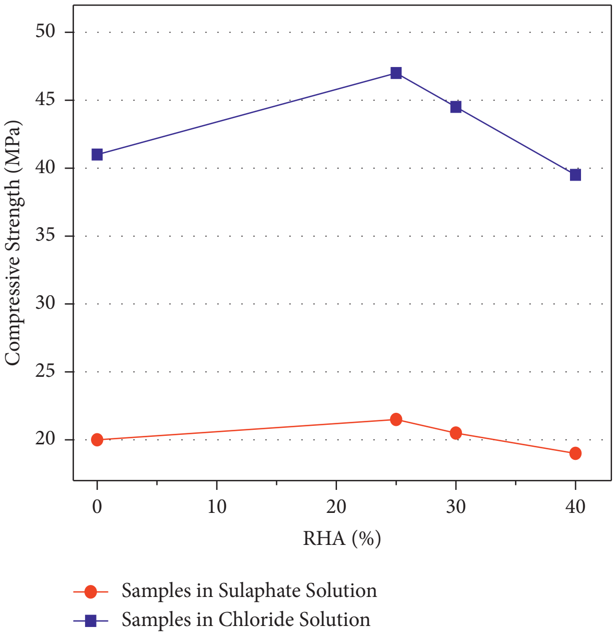


Figure 28: RHA cement mortar in chemical attack [56].

Quedou et al. [66] studied the water absorption capacity of SCBA containing concrete. They placed and cured 15 × 15 × 15 cm concrete cubes in water for 28 and 56 days and then dried in an oven for 72 hr. The study found that there was an increasing trend in the water absorption capacity of the concrete with the addition of SCBA in the concrete mix and similar to [72, 120, 121]. It was observed that increasing SCBA would result in increment of water absorption; however, the water absorption rate decreased with increasing curing period. It might be due to the fact that the presence of pores in SCBA [122]. They noticed that the percentages increased in water absorption ranging from 255% to 488% with respect to the reference concrete mix value. This was attributed to the dense and compact structure of concrete samples decreased the water absorption [123]. According to the result obtained by Ganesan et al. [78], compared to the normal concrete, the saturated water absorption of concrete was decreased, while there was an increment when the percentages of SCBA content increase at 28 days and the optimum level of SCBA was 15% at 90 days curing periods. Figure 26 summarizes the 28-day results of the water absorption based on the above studies.

The test method used by Quedou et al. [66] to analyze the water penetration of concrete was as per [124]: Part 8: 2009. They used 15 × 15 × 15 cm concrete cubes and cured in water for 28 and 56 days. Then, the specimens were placed in an apparatus and applied a water pressure of 500 kPa for 72 hr. After 72 h, the specimens were removed and cleaned to remove excess water. The sample was split into half perpendicular to the face exposed, and the watermark was recorded. They reported that because of high porosity of nature of SCBA, the content addition of SCBA in concrete increased the water penetration rate and incorporates with water absorption capacity of the concrete. Compared to the control mix, at 56 days, a dimension of 33.30% to 133.30% water penetration was observed.

Ganesan et al. [78] investigated the chloride penetration of concrete to evaluate the resistance of concrete to chloride ion penetration in terms of total charge passed SCBA blended concrete samples after 28 days and 90 days of curing in water and conducted as per ASTM C 1202. Figure 27 revealed that the total charge passing through concrete specimens linearly decreases with increase in SCBA content of 25%. At 28 days and 90 days of curing ages, the value of the total charge passed through for 20% SCBA concrete was less than above 50% with respect to the 100% OPC concrete.

Abebaw et al. [21] also performed the effects of bamboo leaves' ash (BLA) addition on sulphate resistance of concrete after 56 days by adding 5% of sodium sulphate solution. They observed the concrete cube samples suffered a strength loss due to the increments of BLA content. It was shown that the percentage strength reductions were 3.37%, 3.93%, 4.63%, and 4.79% for a BLA replacement level of 5%, 10%, 5%, and 20%, respectively. Khan et al. [56] carried out experimental work for the chemical resistance of rice husk ash (RHA) to study the properties of 25%, 30%, and 40% of RHA-blended mortar according to ASTM C722. They studied the effects of aggressive salt solutions containing chlorides and sulphates on the compressive strength of concrete at various dosages of RHA. In addition, they further included 5% ammonium and 5% magnesium chloride to the chloride solutions, whereas sulphate solutions were prepared with 2% calcium sulphate and 2% magnesium sulphate. The actual performed result is shown in Figure 28. Based on the figure, due to the chemical reaction of cements with the salts, the chemical resistance of OPC mortar was lower than mortars containing RHA; this indicates that the increase in ash content caused a significant increase in the sodium sulphate resistance of the concretes [125]. Also, it could be examined that the maximum

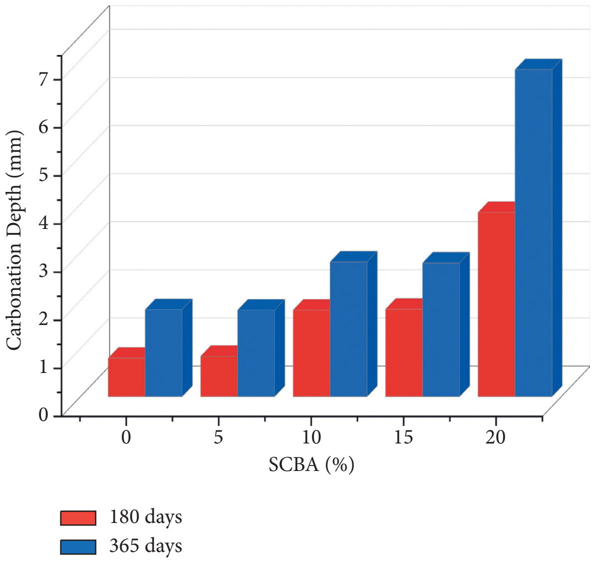


Figure 29: Carbonation depth of OPC-SCBA concrete [66].

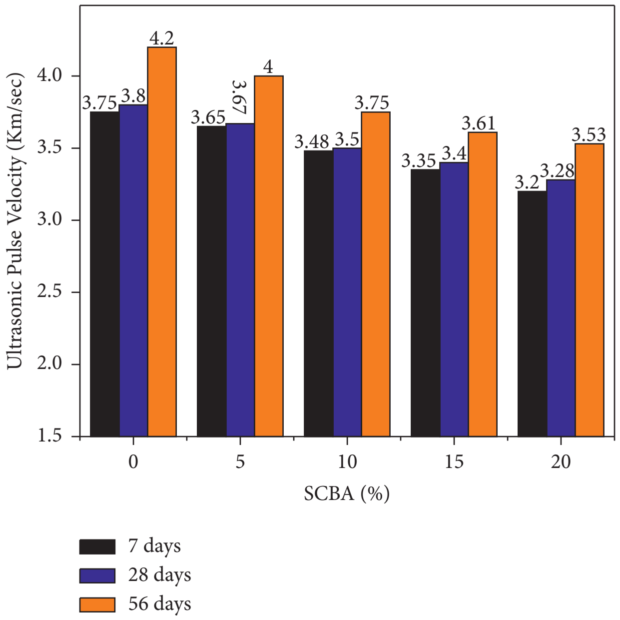


Figure 30: Ultrasonic pulse velocity of OPC-SCBA concrete [66].

Table 13: The energy necessary to produce the cement (En) and the energy performance (Ep) of mortars at 28 days. [24].

Mix samples	E_n (kWh/t)	E_p (kWh/t/MPa)
Control	112.00	3.07
20% BLA	98.56	2.06
10% BLA10% SCBA	98.56	2.16

compressive strength of mortars achieved at 25% cement replacement with RHA. They also found that, after 70 days of submersion in 0.1 N sulphuric acid solution, both the OPC cement and RHAC mortars got disintegrated and were in the deformed shapes. Also, the weight was reduced by about 20% of the original weight.

According to Quedou et al. [66], carbonation test is performed to analyze the reaction of hydrated cement minerals with CO_2 in the presence of moisture, and the test was conducted as per [126] at 180 and 365 days on cylindrical cores of diameter 50 mm which were split into half. They revealed that the carbonation depth was improved with curing period from 180 days to 365 days. In Figure 29, it also examined the increase of SCBA content improved the tendency of carbonation depth from the upper surface layer. They reported that, for 5% replacement of SCBA with cement, the value of 180 days and 365 days carbonation depth was similar with the normal mix.

The purpose of the test is to evaluate concrete porosity and to detect cracks in its membrane [66]. It also performed to check the quality of concrete by passing an ultrasonic pulse through a specimen, and they conducted the test as per [127]: Part 203: 1986. According to the performed investigations shown in Figure 30, the continual addition of SCBA would decrease the velocity of the pulse through the concrete. They also observed that, for each replacement levels of cement with SCBA, there were nearly similar result in the pulse velocity for 7 days and 28 days, but there was an improved result at 56 days. The results demonstrated that the decrease at 28 days for 5%, 10%, 15%, and 20% of replacement of SCBA were 4.1%, 9.4%, 11.2%, and 15.3%, respectively; however, at 56 days of curing, the velocity across the specimens decreased by 3.54%, 9.0%, 11.8%, and 14.6%, respectively.

2.5. Environmental, Economic, and Technical Aspects.

Without taking account the CO_2 emissions linked to transport, the production of 1 ton of cement produces about 1 ton of carbon dioxide and the ashes can be a solution to reduce CO_2 emissions [24]. According to Table 13, the energy consumed to produce 1 ton of binder with agro-industrial ashes was lower than the energy used to produce the same amount of conventional cement. They also

Table 14: Summary of the results of the effects on concrete and mortar.

S. no.	Author	Year	Title	Methods (%, *w/c*)	Results	Optimum level
1				Bamboo leaves' ashes (BLA)		
1.1	Frias et al. [23]	2012	Characterization and properties of blended cement matrices containing activated bamboo leaf wastes	✓10 and 20% ✓0.50 w/c	(i) Demand for water content increased by 19% and 46% to the additions of 10% and 20% BLA, respectively (ii) Setting time delayed with 20% BLA (iii) BLA blended cement had similar volume stability with the control cement paste (iv) Compressive strength slightly reduced, stable volume, andand satisfied ASTM C 618 – 03 requirements.	10%
1.2	Rodier et al. [24]	2019	Potential use of sugarcane bagasse and bamboo leaf ashes for elaboration of green cementitious materials	✓10 and 20% ✓0.50 *w/c*	(i) BLA mineral had higher pozzolanic activity (ii) After 28 days curing ages, there was higher amounts of C-S-H and ettringite hydrations in the BLA sample (iii) All samples of the 48 hrs binary and ternary cementitious decreases in total heat of hydration and the highest reduction was observed at 20% of BLA (iv) 14% increment in compressive strength for 20% of BLA (v) The use BLA ashes would reduce the cost, energy consumed, and environmental impacts	10%
1.3	Moraes et al. [1]	2019	Production of bamboo leaf ash by autocombustion for pozzolanic and sustainable use in cementitious matrices	✓5, 10, 15, 20, 25, and 30 ✓0.50 *w/c*	(i) BLA is classified as high reactive pozzolanic materials (ii) 7 days mortar compressive strength similar with 100 OPC (iii) 30% BLA achieved a strength gain of 56% at 90 days of curing	10%
1.4	Villar-Cociña et al. [25]	2010	Pozzolanic behavior of bamboo leaf ash: characterization and determination of the kinetic parameters		(i) At early stages, BLA showed high reactivity (ii) The one which calcined at 600°C had high pozzolanic reactivity	
15	Villar-Cociña et al. [26]	2016	Pozzolanic characterization of Cuban bamboo leaf ash: calcining temperature and kinetic parameters	✓At 500°C, 600°C and 700°C calcined temperatures	(i) BLA had high reactivity at early ages (ii) The samples calcined at 500°C and 600°C showed similar reactivity, whereas the 700°C one showed less reactivity	

Table 14: Continued.

S. no.	Author	Year	Title	Methods (%, *w/c*)	Results	Optimum level
2	Banana leaves' ashes (BNLA)					
2.1	Kanning et al. [36]	2014	Banana leaves' ashes as pozzolan for concrete and mortar of Portland cement	✓5, 7.5, and 10% for mortar with 0.59, 0.58, and 0.57 *w/c*, respectively ✓10 and 20% for concrete with 0.50 *w/c*	Mortar (i) All samples showed smaller deformation that the control mix Index of water retention higher than the reference one (ii) The specific mass is 3% higher than 100% OPC (iii) For 10% BLA, tensile and compressive strength increased by 10% and 25%, respectively, compared to the control mix Concrete (i) For 10 and 20% BLA, the 28 days mechanical strength were 25% and 40% higher than 0% BLA	(i) 10% for mortar (ii) 7.5% for concrete
2.2	Dhage et al. [37]	2020	Experimental study on partial replacement of cement by banana leaves' ash	✓20, 30, 40, and 50% ✓0.50 *w/c* ✓for C-30 concrete grades.	(i) 28% BLA achieved standard consistency (ii) Initial and final setting time reduced by 12% and 4.7%, respectively (iii) The compressive strength decreases in increment of BLA content (iv) At 28 and 56 days, split tensile, and flexural strength increased by 30% BLA. (v) For 10% BLA, acid and sulphate reduces the volume of voids (vi) Sulphate salts and calcium acids reduces weight and compressive strength of concrete	30%
3	Corncob leaves' ashes (CCA)					
3.1	Adesanya and Raheem [41]	2009	A study of the workability and compressive strength characteristics of corn cob ash blended cement concrete	✓2, 4, 6, 8, 10, 15, 20, and 25% ✓0.50 *w/c* for 1 : 1.5 : 3 mix ratio ✓0.60 *w/c* for 1 : 2 : 4 mix ratio 0.70 *w/c* for 1 : 3 : 6 mix ratio	(i) Setting time, slump decreases and compacting factor increases as CCA increases (ii) Compressive strength decreased with increment of CCA content (iii) At 120 days, for 4% BLA the compressive strength gained higher than the control mix	4%
3.2	Owolabi et al. [42]	2015	Effect of corncob ash as partial substitute for cement in concrete	✓0, 5, 10, 15, and 20% ✓0.65 w/c	(i) Workability decreased as the CCA increased. Compressive strengths reduced as the CCA % increased.	5%
3.3	Singh et al. [43]	2017	A sustainable environmental study on corn cob ash subjected to elevated temperature	✓0, 5, 10, 15, and 20% ✓Temp of 150, 300, 450, and 600°C for 2 hrs. ✓0.45 w/c	(i) Compressive strength of all mixes increases up to 300°C (ii) At 300°C, compare to the reference mixes, the increase in compressive strength was 13.18, 16.20, 11.09, and 14.29% for 5, 10, 15, and 20% CCA	10% 300 ^{0}C

Table 14: Continued.

S. no.	Author	Year	Title	Methods (%, *w/c*)	Results	Optimum level
3.4	Desai [45]	2018	Experimental study on corn cob ash powder as partial replacement of cement in concrete	✓10, 20, and 30% ✓0.55 w/c	(i) Compared to the control mix, for 20% CCA, the compressive strength decreased by 20.10 and 9.11% at 7th and 28th days curing ages, respectively (ii) For the same CCA % and curing ages, the tensile strength reduced by 20 and 9% (iii) For 20% CCA, at the ages of 90 days, the flexural strength slightly decreased by 2.28%	10%
4				Groundnut shell ashes (GNA)		
4.1	Buari et al. [51]	2019	Short term durability study of groundnut shell ash blended self-consolidating high performance concrete in sulphate and acid environments	✓10, 20, 30, and 40% ✓0.37 w/c	(i) Slump decreased with increase in GNA percentage (ii) For all mixes, the concrete takes lower flow time in molds (iii) Segregation resistance increased with increase in GNA percentages (iv) Except 10% GNA, the compressive strength decreased with increase in GNA content	10%
4.2	Usman et al. [50]	2019	Influence of groundnut shell ash on the properties of cement pastes	✓10, 20, 30, 40, and 50% ✓0.36 w/c	(i) Rate of water demand increased with increasing GNA content and it was higher than by 100 and 146% with GNA content of 30 and 50%, respectively (ii) GNA retards the setting time but not exceeds the min ASTM standards (iii) Soundness improved with GNA % (iv) Compressive strength highly decreased with GNA levels increased (v) For 40% GNA, the compressive strength improved by 270% at 28 days curing age	
5				Rice husk ashes (RHA)		
5.1	Raheem and Kareem [58]	2012	Chemical composition and physical characteristics of rice husk ash blended cement	✓5, 7, 11.25, 15, 20.25, and 25%. ✓For mortar	(i) Setting time increased with the inclusion of RHA up to 15% (ii) With increment of RHA content, there were improvement in soundness and consistency (iii) For early curing ages, the mortar compressive strength decreases with increase in RHA content for all mixes, but at later ages (90 days) 5% and 7% RHA have similar strength with the normal mix	7%

Table 14: Continued.

S. no.	Author	Year	Title	Methods (%, *w/c*)	Results	Optimum level
5.2	Jamil et al. [106]	2013	Pozzolanic contribution of rice husk ash in cementitious system	✓0, 5, 10, 15, 20, 25, 30, and 35% ✓For mortar and concrete	(i) Up to 30% replacement of RHA content, the compressive strengths of both mortar and concrete were better than the control mix. The maximum strength was gained at 15% and 20% of RHA for mortar and concrete, respectively.	(i) 15% for mortar (ii) 20% for concrete
5.3	Khan et al. [56]	2013	Reduction in environmental problems using rice-husk ash in concrete	✓25, 40, and 50 without superplasticizers (SP) and 25 and 40% with SP ✓0.70 *w/c* for both mixes	(i) For all mixes, the compressive strength of concrete with SP was better than that of without SP (ii) Compared to 100% OPC concrete, there were reductions in the compressive strengths of both samples at all curing periods (iii) RHA mixed concrete beams have low resistance to load at failure and deflection and 25% RHA concrete beams gave very well flexure (iv) 20% RHA concrete mix have a good resistance to sulphate and chloride chemicals attack	25% for both with and without SP
5.4	Zareei et al. [59]	2017	Rice husk ash as a partial replacement of cement in high strength concrete containing micro silica: Evaluating durability and mechanical properties	✓0, 5, 10, 15, 20, and 25% ✓40% *w/c*	(i) At all stages of the concrete ages, the compressive strength of all concrete samples was increased with additions of RHA content with relative of the normal mix and higher strength was achieved at RHA replacement level of 20% (ii) The saturate water absorption capacity of all RHA concrete mixes were reduced compared to the control one (iii) 25% RHA content has improved the permeability properties of blended concrete	20%
5.5	Zareei et al. [59]	2017	Study on concrete with partial replacement of cement by rice husk ash	✓0, 5, 10, 15, and 20% ✓0.37 *w/c*	(i) The workability of concrete decreased with RHA additions and the concrete mix requires additional water to be workable (ii) Except for 10% replacement of OPC with RHA, the percentages replacement of cement with RHA would reduce the compressive and split tensile and flexural strength of concrete (iii) At 28 days curing period, for 10% RHA content the compressive, tensile and flexural was improved by 8.5, 10.5, and 20% from the control mix, respectively (iv)The water absorption of concrete increased with increase in RHA	10%

Table 14: Continued.

S. no.	Author	Year	Title	Methods (%, *w/c*)	Results	Optimum level
6			Sugarcane bagasse ashes (SCBA)			
6.1	Ganesan et al. [78]	2007	Case study: sustainable concrete: potency of sugarcane bagasse ash as a cementitious material in the construction industry	✓5, 10, 15, 20, 25, and 30% ✓0.53 *w/c*.	(i) Water consistency and initial and final setting time increases with increase in SCBA content (ii) No need of additional water demand to make the concrete workable (iii) At 7- and 28-days curing periods, up to 15% SCBA, the compressive strength increases and further addition of SCBA would decrease (iv) At all stages, the strength was higher than the target strength (v) Compared to the normal mix, the 28 days split tensile strength improved for 5, 10, 15, and 20% SCBA (vi) The water absorption was increased with SCBA additions and for 30% SCBA it was 30% higher than the control mix (vii) Compared to the reference mix, the chloride penetration was decreased with increase in SCBA at 28 and 90 days	15%
6.2	A. Asma et al.	2014	Research article: Compressive strength and microstructure of sugarcane bagasse ash concrete	✓5, 10, 15, 20, 25, and 30% ✓0.38 w/c superplasticizer	(i) The slump value linearly increased with increment of SCBA content, and it was more workable than the reference mix (ii) 5, 10, 15, and 20% of SCBA containing concrete mix showed higher compressive strength than the normal mix (iii) The addition of SCBA content improved the ITZ gap length between aggregate and cement paste, and for 15% SCBA, there was no any gap, hence increasing the microstructure strength of the concrete	20%
6.3	Mangi et al. [80]	2017	Utilization of sugarcane bagasse ash in concrete as partial replacement of cement	✓5 and 10% ✓For C-15 and C-20 concrete	(i) For both grades of the concrete, the concrete became more workable than the control mix and higher slump value was obtained at 10% of SCBA (ii) At 10% SCBA, the slump value increased by 28% and 45% for C-15 and C-20 concrete, respectively, with respect to the 0% SCBA (iii) The compressive strength of all concrete mixes was greater than the reference mix one at all stages of the concrete ages and maximum result was recorded at 5% replacement of SCBA	5%

Table 14: Continued.

S. no.	Author	Year	Title	Methods (%, *w/c*)	Results	Optimum level
6.4	Quedou et al. [66]	2021	Effect of corncob ash as partial substitute for cement in concrete	✓0, 5, 10, 15, and 20% 0.65 *w/c*	(i) Workability decreased as the CCA increased. Compressive strengths reduced as the CCA % increased but increased as the number of days of curing increased for each percentage CCA replacement.	5%

examined that the cost of 1 ton of cement was US $32 in Brazil [128], and the price for average electricity was US $ 0.147/kWH [129]; however, the production cost for 1 ton of ashes was estimated about US $24 including 50% of Brazilian taxes and labor [130], as well as Brazilian industrial sector profit margin of 8% [130]. They concluded the use of ashes as partial replacement of cement can reduce the cost of cement.

Following, the overall results of agricultural crop waste products as pozzolanic cementitious materials on the properties of concrete and mortar are summarized and shown in Table 14.

3. Conclusion

Based on the detailed reviews of the above studies on the pozzolanic characterizations, workability, mechanical, and durability properties of the use agricultural waste products as a partial replacement of cement, the following conclusions can be drawn:

(i) The X-ray diffraction investigations revealed that BLA, CCA, RHA, and SCBA are alumino-siliceous materials satisfying the properties of pozzolanic materials as per ASTM C618. They are composed of amorphous silica which can undergo a secondary reaction in cement replacement.

(ii) Physically, BNLA, CCA, GNA, RHA, and SCBA have smaller particle size and higher surface area than cement particle. RHA has high porous and irregular shape, while SCBA has smooth surface and prismatic shape.

(iii) The workability of fresh concrete showed a decreasing trend with the increase in the content of BLA, CCA, RHA, and SCBA. This can be explained that their higher surface area and porous nature absorbed the concrete mixing water. On the other hand, the mechanical performance of concrete with partial replacement of cement by BLA, RHA, and SCBA showed improvement since the amorphous silica involved in secondary reaction to produce densified tetrahedral gel.

(iv) The increased mechanical performance of concrete mixes with BLA, RHA, and SCBA showed improvement on morphology and durability of concrete.

In general, it can be concluded that agricultural crop products have greater potential to partially replace cement up 10%, thereby reducing environmental pollution and energy demand of cement production.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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