Civil Engineering and Architecture 11(6): 3479-3487, 2023 http://www.hrpub.org
DOI: 10.13189/cea.2023.110618

Properties of Concrete and Mortar Containing Locust Bean Pod Ash as Cement Replacement: A Review

Felix Nkapheeyan Isa[1,*], Megat Azmi Megat Johari[1], Iorwuese Anum[2], Solomon Maxwell Soji[2], Changlia Hassan Salihu[1,2], Julius Lananzakan Agabus[2]

[1]School of Civil Engineering, Engineering Campus, Universiti Sains Malaysia, Malaysia
[2]Department of Building, Modibbo Adama University, Nigeria

Received April 24, 2023; Revised August 4, 2023; Accepted September 8, 2023

Cite This Paper in the Following Citation Styles

(a): *[1] Felix Nkapheeyan Isa, Megat Azmi Megat Johari, Iorwuese Anum, Solomon Maxwell Soji, Changlia Hassan Salihu, Julius Lananzakan Agabus, "Properties of Concrete and Mortar Containing Locust Bean Pod Ash as Cement Replacement: A Review," Civil Engineering and Architecture, Vol. 11, No. 6, pp. 3479 - 3487, 2023. DOI: 10.13189/cea.2023.110618.*

(b): *Felix Nkapheeyan Isa, Megat Azmi Megat Johari, Iorwuese Anum, Solomon Maxwell Soji, Changlia Hassan Salihu, Julius Lananzakan Agabus (2023). Properties of Concrete and Mortar Containing Locust Bean Pod Ash as Cement Replacement: A Review. Civil Engineering and Architecture, 11(6), 3479 - 3487. DOI: 10.13189/cea.2023.110618.*

Abstract Global infrastructural development is one of the causes of environmental degradation resulting from the high usage of cement and other nonrenewable materials. These activities have led to a shift in research in the building industry towards the employment of abundant natural raw materials. Locust bean pod (LBP) is a waste product gotten from the harvest of African Locust Bean (Parkia biglobosa). Existing literatures have shown the immense potentials of using locust bean pod ash (LBPA) as a substitute for cement in cement-based products, thus drawing research attention on the subject. This paper presents a conspectus of previous researches on the use of LBPA for concrete and mortar production. Consequently, the effects of LBPA on slump, compressive, flexural, tensile strength as well as some durability properties are discussed. It was concluded that LBPA is pozzolanic and can be satisfactorily utilized as a supplementary cementing material (SCM) to enhance concrete properties with an optimum replacement range of 5 to 15%. The study highlights areas of further research and recommends the adoption of this emerging innovation as a result of its established performance and its potentials for sustainable concrete manufacture.

Keywords Concrete, Durability, Locust Bean Pod Ash, Supplementary Cementitious Materials, Properties

1. Introduction

Global infrastructural development has led to drastic surge in the usage of concrete, thereby retaining its spot as the most commonly used building material globally [1]. Concrete is made of ordinary Portland cement (OPC), aggregates, water and in some cases admixtures [2]. Thus, the construction industry is highly dependent on OPC which is the most influential constituent of concrete [3]. However, OPC is expensive, and its production has a negative effect on the environment; cement manufacture is the tierce source of CO_2 emission behind fossil fuels and land-usage due to deforestation [4], [5]. It is projected that the emanation of CO_2 is between 0.8–1.3 tons per ton of cement making and accounts for 8–10% of the total global CO_2 emission [6]. Thus, the need to replace cement so as to reduce the greenhouse gases is immensely crucial [7]. In a bid to reduce cement consumption globally, industrial waste products and agricultural wastes have been explored as SCM [8]. These include silica fume [9], fly ash [10], slag [11], glass powder [12], bottom ash [13], rice husk ash [14], groundnut husk ash [15], among others. Pozzolans have been found to increase concrete's durability, lessen negative environmental consequences, and lower the cost of concrete [16], [17]. Due to the qualities of mortar and concrete containing such materials exhibiting tremendous potential, the use of agricultural wastes as SCMs has intensified [18]. Over 50% of the agricultural biomass worldwide is made up of crop remains [19]. One of such agricultural wastes is the LBP obtained from the harvest of the African Locust Bean tree (Parkia biglobosa).

The perennial tree species native to the west African savannah is utilized for a variety of purposes, including food, condiments, medicine and manure [20]. Nearly 201,000 tons of locust bean fruits are harvested annually in northern Nigeria alone [21]. The harvested fruit, which is the most valuable component of the tree, has two components: the seed and yellow pulp making up 61% of the fruit with the pods (waste material) accounting for 39% by weight [22]. The fruit is typically opened up so that the pulp and seeds can be taken out. After that, the pods are thrown away, burned, and the ashes are placed in landfills; constituting environmental concerns. The environment and people's health are negatively impacted by this disposal methods [23]. There is a need to effectively dispose this waste to ameliorate the effect on the environment. Proper waste management like recycling for use in construction and other areas can be beneficial economically with reduction in concomitant environmental effects. However, disposal of these and other wastes is a major challenge. The basic and most common way of disposal of the waste is to have the pods and the stem burnt in an open area or left to decay naturally which is detrimental to the environment [24], [25]. Thus, controlling agricultural waste like LBP and looking for creative, long-lasting solutions to reuse it is essential and ought to be a global priority. To resolve this dilemma, a significant amount of garbage needs to be transformed into a worthwhile, environmentally beneficial product with a long lifespan. Thus, recycling LBP by utilizing it as building material is a sustainable alternative that will protect the environment [18].

Hence, numerous methods for integrating LBP in the creation of environmentally friendly building materials have been established in earlier studies. These include use of ground LBP (powder) for soil stabilization, extract for production of sandcrete blocks and ash (most widely used form) for production of concrete and mortar [26], [27]. This is aimed at agricultural waste reduction on the environment, decreasing depletion of natural resources, reduced CO_2 emissions released in cement manufacture as well as construction cost reduction.

LBPA is produced when LBP is burnt. The ratio of the LBPA to the pod obtained from the incineration is 1:25 [28]. Figure 1 shows pictures of Locust bean tree, LBP, calcination of LBP and LPBA.

Previous studies revealed that LBPA improves strength and durability of concrete and mortar when used to partially replace cement. It is also an effective soil stabilization agent [20], [29], [30]. Consequently, research efforts aimed at improving concrete and mortar performance have stimulated research into the use of LBPA in various concrete and mortar applications. Therefore, a comprehensive review and compilation of various research efforts utilizing LBPA as SCM for concrete and mortar production becomes necessary. This would contribute to the body of existing knowledge by providing a better understanding of the subject as well as providing a compendium of empirical data on the subject for future research directions. This paper aims to provide a review of existing research on the use of LBPA as a substitute for cement in cement-based products.

Figure 1. Locust bean tree, LBP, calcination of LBP and LBPA

2. Methodology

Previous works related to the topic were identified through search in Google Scholar, Scopus, and Web of Science as information sources for this review. The terms “locust bean”, “locust bean pod” “locust bean pod ash”, and “locust bean pod ash concrete” were used in the search. The inclusion criteria took into account the papers' implementation of an empirical investigation into the effects of LBPA on the characteristics of concrete and mortar. Similarly, currency where only articles published between the year 2010 to 2023 and peer-reviewed journal articles were considered. Articles that were irrelevant and did not belong to the aforementioned category were not included in the review. The selected articles were examined, analyzed and the key qualities of concrete and mortar are compared and reported in this article.

3. Chemical Properties of LBPA

Different research works have been carried out using LBPA sourced from different parts of Nigeria and sub-Saharan Africa, as partial cement replacement. The locust bean pods are normally allowed to dry and then burnt in a furnace. The nature of the LBPA produced is reliant on the calcination temperature and duration as low temperature results in crystalline powder whereas amorphous powders would be produced at high temperature [31]. The calcination temperatures range from 500– 900 ℃. Yisa and Jimoh [28] recommended a temperature of 500 ℃. XRF analysis showed that the LBPA was a Class C pozzolan based on ASTM C618 [28] having a combined content of 63.57% for SiO_2, Al_2O_3 and Fe_2O_3. Auta and Kabiru [26] got 77.81% of SiO_2, Al_2O_3 and Fe_2O_3 content. Yalley [17] and Ochola et al. [32] employed temperature of 500 ℃ whereas Afolayan et al. [33] used open burning to obtain LBPA for their work. Also, Ojewumi et al. [34], Ali et al. [35] and Ikumapayi et al. [36] heated the LBP in a furnace at 500 ℃ for two hours whereas Ikumapayi [37] resorted to 600 ℃ for 1hour. Conversely, Olubajo et al. [38] calcined LBP at 800, 850 and 900 ℃ with calcination periods of 1-2 hours at 50 ℃ and 30 minutes interval. XRF analysis revealed summation of SiO_2, Al_2O_3 and Fe_2O_3 to be less than 50%. Similarly, Ikumapayi [39] got 25.2% of SiO_2, Al_2O_3 and Fe_2O_3 content.

In all cases, the LBPA obtained is allowed to cool and is sieved through BS No. 200 or 150 µm apertures to meet the requirements for pozzolans [40]. Various results of the chemical analysis of the LBPA revealed that the sum of SiO_2, Al_2O_3 and Fe_2O_3 ranged from 25.2 to 77.81% contingent on the temperature and duration of calcination. Table 1 shows the chemical composition of LBPA by different authors.

4. Research Findings on the Use of LBPA in Concrete and Mortar

Research findings associated with the uses of LBPA on the features of concrete are subsequently presented in this section. The properties of concrete and mortar covered encompass fresh, mechanical and durability properties. Table 2 gives a summary of some previous studies where LBPA was utilized in concrete and mortar production.

Table 1. Chemical Composition of Locust Bean Pod Ash from Previous Works

Serial	Composition	Reference					
		Adama and Jimoh (2012) [41]	Akpenpuun et al. (2019) [29]	Yalley (2019) [17]	Auta & Kabiru (2020) [26]	Olu et al. (2020) [42]	Afolayan et al. (2018) [33]
1	SiO_2	39.01	40.25	40.07	64.659	9.48	39.01
2	Al_2O_3	13.05	13.15	14.40	9.785	2.00	13.05
3	Fe_2O_3	11.51	9.00	12.51	3.365	18.94	11.51
4	CaO	15.71	12.50	15.71	7.416	19.42	15.71
5	K_2O	5.62		4.65	2.626	27.54	
6	MgO	2.01	2.03	2.0	3.659	5.95	2.01
7	Na_2O	1.21		1.20	0.926	0.44	
8	SO_3		1.50		1.990	0.70	
9	P_2O_3	5.82		5.64	3.449	7.71	

Table 2. Summary of Selected Previous Studies Using LPBA as Reported in the Literature

S/N	Authors	W/b Ratio	Method	% Replacement	Strength Properties (N/mm^2)	Summary of Findings
1	Afolayan et al. (2018) [33]	0.55	Cement replacement	0, 5 to 50% in increment of 5%	Compressive: 25, 22.33, 19.0 (0, 5, 10%)	Increased compacting factor/slump, decrease in strength with addition of LBPA
2	Auta et al. (2020)[43]	0.50	Cement replacement	0, 5, 10, 15 and 20%	Flexural: 9.2, 9.0, 7.79, 6.57 and 4.5	Increased workability, increased flexural strength with curing time.
3	Akpenpuun et al. (2019) [29]	0.55	Cement replacement (Mortar)	0, 10, 15, 20 and 30%	Compressive (mean): 22.5, 14.27, 13.0, 14.8, and 10.8	Decreased workability, increased compressive strength up to 15% LBPA replacement.
4	Ali et al. (2019) [35]	X	Cement replacement	0, 5, 10 and 15%	Compressive: 28.33, 23.0, 22.33, and 13.43	Reduction in compressive strength but increased with curing age.
5	Ndububa and Uloko (2015) [44]	X	Cement replacement	0, 5, 10, 15, 20 and 25%	Compressive: 22.19, 20.92, 13.70, 12.44, 12.13 and 12.03	Decreased compressive strength; strength increased with curing age and decreased water absorption.
6	Ochola et al (2021) [45]	X	Cement replacement	0, 5, 10, 15 and 20%	Compressive: 22.11, 23.62, 19.88, 16.18 and 15.18	Reduced compressive strength.
7	Yalley PP (2019) [17]	0.5 ± 0.02	Cement replacement	0, 40, 50 and 60%	Compressive:40, 42, 39.8 and 38.2 Tensile: 3.8, 4.5, 4.2 and 3.1	Increased compressive, tensile and flexural strengths.
8	Olubajo et al. (2020) [38]	0.4	Cement replacement	0, 2.5, 5, 7.5, and 10%	Compressive: 48.18, 46.0, 40.09, 41.92 and 43.18 Flexural: 6.80, 6.43, 6.21, 6.03 and 6.99	Increased strength with curing age.

4.1. Fresh Properties of Concrete and Containing LBPA as Cement Replacement

4.1.1. Workability

Incorporation of LBPA affects the workability of concrete and mortar. Olu et al. [42] examined the consistency of Portland cement blended with LBPA and eggshell ash (ESA) and found a variation in consistency at varied LBPA/ LBPA-ESA proportions as cement substitutions were increased from 0-10% by mass. The gain in consistency according to the authors is attributed to the depletion of C_3S in cement, the unburnt carbon in the ashes and perviousness of LBPA. Ja'e et al [46] reported that consistency increased with an increase in LBPA content. OPC was replaced with 5%, 10%, 15% and 20% of LBPA by mass by the authors. Akpenpuun et al. [47] reported reduced workability of mortar as LBPA was increased. The workability was evaluated at 0, 10%, 15%, 20% and 30% cement replacement by mass. The authors concluded that the decrease in slump on addition of LBPA could be ascribed to the permeable nature of the LBPA owing to the occurrence of macro and meso-pores within and on the surface of the material. Similarly, Ali et al. [35] reported a decrease in slump values with increase in LBPA in grades 20, 25 and 30 concrete and opined that the reduction in slump was due to the absorption of some quantity of water by the LBPA particles. In the same vein, Afolayan et al. [33] stated that compacting factor decreased as the LBPA content increased to a minimum value of 0.86 at 30% LBPA content and thereafter increased. The compacting factors range between 0.87 and 0.92 for all the mixes. OPC was replaced up to 50% using 1:2:4 concrete and 0.55 w/b ratio. Furthermore, Auta et al. [43] stated that both slump and compacting factor tests revealed that more water was required to make the concrete workable as the LBPA content was increased. The authors examined flexural strength of reinforced and revibrated concrete beams by replacing OPC with 0, 5, 10, 15, and 20 % LBPA.

4.1.2. Initial and Final Setting Times

The setting times increased with the increase in LBPA, indicating delay in both initial and final setting times [46]. Similarly, Olu et al. [42] examined the setting times of mortar blended with LBPA and ESA and reported a series of accelerations and retardations as the cement replacement levels increased. The presence of unburnt carbon in the ashes, the formation of $Mg(OH)_2$ coupled with diminution of the clinker content were the reasons for the extension in the setting time of the cement blends. The retardation in their setting times was related to the attenuation of clinker content or development of magnesium hydroxide and the existence of carbon in the ashes. Akpenpuun et al. [29] noted an upsurge in both setting times of mortar as the replacement level of cement with LPBA increased. At 30%, the LBPA mortar portrayed a rise in the initial setting time by 66.8%, whereas at the equal replacement level extended the final setting time comparative to control by 39.7%. The fineness of LBPA was reported to have significant influence on both setting times.

4.2. Mechanical Properties of Mortar and Concrete Containing LBPA

4.2.1. Compressive Strength

The presence of LBPA significantly affects the compressive strength of concrete and mortar. Auta and Kabiru [26] probed re-vibrated LBPA concrete's compressive strength using a concrete mix ratio of 1:2:4 and a water-binder ratio of 0.6 at 5% to 30% replacement. The strength increased gradually with curing age and a maximum compressive strength of 28.44 N/mm^2 at an hour re-vibration was attained at 28 days for 5% of LBPA against the 22.27 N/mm^2 for the control. The authors recommended 5% as optimum replacement level. Similarly, Ali et al. [35] evaluated the compressive strength of concrete utilizing locust bean waste ash (LBWA) in three different concrete grades: 20, 25, and 30 at 0%, 5%, 10%, and 15% cement substitutions. The results showed a substantial reduction in the concrete's compressive strength upon incorporation of LBWA but with gradual strength gain with longer curing periods. In a quaternary blend, Ochola et al. [30] investigated the compressive strength of concrete using sugarcane bagasse ash (SCBA), LBWA and alkaline activated Metakaolin (MK) in two grades of concrete; 20 and 25 at 0, 5, 10 and 15% substitution. The results revealed significant reduction in compressive strength of concrete utilizing pozzolans; up to 15% cement can be replaced by LBWA. Contrariwise, Yalley [17] evaluated the effects of high amount of LBPA on compressive strength of concrete at 40%, 50%, and 60% replacement by volume at 0.50 ± 0.020 w/b ratio. A reference concrete was proportioned to a compressive strength of 40 MPa after 28 days. The compressive strength increased with curing period with LBPA concrete gaining higher early compressive strength than the control. The author opined that the early effect of LBPA may be due to its influence on accelerating the pozzolanic transformation of C_3S, C_2S and CH into the C-S-H gel which were responsible for the strength improvements of the concretes. For the 40% replacement, the strength attributes were better improved. On examination of the compressive strength of OPC mortar blended with LBPA and ESA, Olubajo et al. [38] found that all blends had an increase in compressive strengths as the curing day advanced with some having improved strength in comparison to the control. The increased strength was attributed to pozzolanic action and the high potassium concentration from LBPA whereas the late strength gains are attributed to the increased potassium content by an increase in LBPA content resulting in a gradual strength gain. While examining the influence of LBPA on mechanical and structural features of mortars at substitution levels of 0%, 10%, 15%, 20% and 30% by mass and water/cement ratio of 0.55 and 1% SP, Akpenpuun et al. [47] found an increase in strength of LBPA mortar up to 15% and thence a decline. Maximum compressive strength ranged from 38.3 and 65 MPa after 7 to 28 days of curing.

Ikumapayi [18] assessed the proficiency of LBPA concrete. A mix ratio of 1: 2: 4 with cement replacement intervals from 1% to 25% and cured for up to 56 days. The maximum compressive strength was obtained at 8% LBPA. The study concluded that up to 12% OPC could be substituted by LBPA. Furthermore, Afolayan et al. [33] used LBPA to replace OPC at 0%, 5%, 10%, 15%, 20%, 25%, 30%, 35%, 40%, 45% and 50% by weight using 1:2:4 concrete at w/b ratio of 0.55. The target strength of 20 N/mm^2 was achieved at replacement levels of 0% (25.00 N/mm^2) and 5% (22.33 N/mm^2). The results also showed a significant reduction in compressive strength at 10 – 15%. According to the authors, up to 5% of cement LBPA should be replaced in concrete without impairing its compressive strength.

4.2.2. Tensile and Flexural Strengths

Yalley [17] appraised the splitting tensile strength of LBPA concrete with 20, 40, and 60% cement replacement level using cylindrical specimens of diameter of 150 mm and height of 450 mm. The tensile strengths of 20 and 40% LBPA concrete were higher than that of the control. The strength gain was attributed to the large surface area of LBPA which promoted the pozzolanic reaction to form C-S-H gel. The tensile strength consistently increased with increase in curing age for all concrete mixtures with 40% LBPA concrete exhibiting the highest tensile strength at 28 days. In the same vein, Auta et al. [43] stated that the flexural strength of LBPA revibrated concrete beams was higher than that of the non-vibrated and the strength increased at initial stage of revibration at 10th and 20th minutes with a later gradual decrease from the 30th min to 60th minutes. Revibration has a positive effect on 5% LBPA concrete. The authors attributed the increase in strength to $Ca(OH)_2$ and densification due to vibration. Similarly, Olubajo et al. [38] examined the flexural strength of OPC-LBPA-ESA mortar using replacement levels of 0-10%. All mortars experienced a rise in the flexural strengths as the curing period advanced. It was also observed that some blends had boosted strength in comparison to the control.

From the foregoing, the compressive, tensile and flexural strength of concrete and mortar are said to be most effectively influenced by replacement level, according to all research. They all concurred that adding more LBPA would have a negative impact on the compressive strength and other characteristics of concrete or mortar. All prior findings on compressive strength show the same pattern. The compressive strength decreases as the LBPA content increases. Additionally, the types and ratios of the components, the quality and grade of the cement, the w/c ratio, and particle size are other elements that have a considerable impact on the qualities of the cement composites. Moreover, there is no specific mix design or optimal LBPA replacement level. Each author instinctively decides on their production parameters. There is need for standardized design and optimum substitution level. However, 5 to 15% optimum has been proposed by most researchers. Additionally, more studies are required on the other mechanical properties in order to appreciate LBPA's applicability. Moreover, since the LBP is sourced from different locations and calcined at different temperatures, the chemical compositions of LBPA vary. The application of LBPA in concrete and mortar is still limited, hence the dearth of literature on LBPA.

4.3. Durability Properties of Mortar and Concrete Containing LBPA

The durability properties are paramount since they have a substantial impact on the performance of the concrete. The durability depends mostly on the constituent materials and is governed by the permeability and exposure conditions [2]. Yalley [17] examined the durability properties of LBPA concrete in terms of water absorptivity, sulphate resistance and corrosion resistance. A control concrete was designed to attain 28-day compressive strength of 40 MPa. LBPA was utilized at 40, 50, and 60% in producing concretes at a w/b ratio of 0.50 ± 0.02. LBPA concretes were either comparable or superior to the control in terms of durability with 40% being the best. The corrosion resistance of 40 and 50% LBPA concrete was better than the control concrete. LBPA concrete composite portrayed substantial reduction in the absorptivity from 10.4% for 0% LBPA content to 7.2%, 8.5%, and 8.8% for 40%, 50% and 60% LBPA respectively**.** The strength decreased by 43%, 28%, 32% and 38% for 0, 40, 50 and 60% respectively after immersion in 10% sodium sulphate solution for 30 days at 25 ℃. Similarly, Ikumapayi et al. [48] examined the drying shrinkage of LBPA concrete with the results showing that the concrete made with LBPA at 12% replacement depicted a more steady and superior shrinkage resistance than the control at 56 and 90 days. Again, Ikumapayi and Akingbomire [49] reported that LBPA improved the autogenous shrinkage resistance of the mortar. They evaluated the effects of LBPA on autogenous shrinkage strain using cylindrical mortar specimens of 75 mm x 300 mm dimension and the volume changes were measured for the concretes. The results revealed that the LBPA improved the autogenous shrinkage of the mortar with 12% being the optimal.

The use of pozzolanic materials reduces the permeability of concrete due to conversion of calcium hydroxide $Ca(OH)_2$ otherwise soluble and leachable into cementitious compounds [50]. Ikumapayi et al. [36] investigated the permeability of chloride ion in LBPA concrete. Using the Rapid Migration Test (RMT) set up for concrete specimen 50 mm thick and 100 mm in diameter with an applied voltage of 10V, 750 ml of 10%NaCl solution and 300 ml of 0.1NaOH were used. LBPA concrete had a better penetration resistance to chloride ion than the control. The increased chloride penetration resistance was due to reduced average pore size of the concrete and the improved interfacial zone. It is markworthy that durability properties such as water absorption, sorptivity, resistance to acid attack, chloride penetration and drying shrinkage influence the long-term performance of the cementitious system [51]. However, the durability of LBPA concrete and mortar remains untapped, hence the dearth of literature on these properties. Thus, the need for in-depth studies on its durability properties.

5. Conclusions

Based on the reviews of available literature on the application of LBPA in concrete and mortar, available data reveals that LBPA has pozzolanic properties and can be used as an SCM. Incorporating LBPA in concrete and mortar is an appropriate and environmentally friendly method of waste disposal. The chemical composition of LBPA is dependent on the source and calcination temperatures. The calcination at 600ºC for 2 hours is adjudged to be the most suitable parameter. Workability and setting times of concrete and mortar tend to decrease with increased LBPA content. In most studies, the strength (compressive, tensile and flexural) of LBPA concrete and mortar decreased with an increase in LBPA content. These attributes are significantly impacted by the LBPA content. However, there is no standard design mix or optimal replacement level for LBPA; each author instinctively selects their design parameters and replacement levels. It has been advised to use LBPA up to a particular percentage (5–15%) for load-bearing constructions. Concrete containing LBPA was observed to improve the durability of concrete in terms of resistance to sulfate attack, chloride ion penetration and sorptivity. It is noteworthy that majority of the studies did not consider curing period beyond 28 days, hence the lack of information on the long-term strength of LBPA concrete. Additionally, most studies considered the mechanical properties without recourse to durability, hence little information is available on the durability properties of LBPA concrete and mortar. The study has contributed to knowledge by providing empirical data and suggested future research directions for the use of LBP in concrete production.

6. Recommendation for Further Studies

a) More in-depth studies on mechanical properties of LBPA concrete and mortar as well as long-term strength beyond 28 days need to be evaluated.
b) The durability properties of LBPA concrete such as fire and thermal resistance, acid and chemical attacks need to be explored.
c) The effect of adding other pozzolans with LBPA in concrete and mortar need to be studied.
d) There is need for studying and analyzing the effects of LBPA in geopolymer, high-strength, high performance and self-compacting concrete.
e) Despite all the studies, there is no statistical model for prediction of LBPA concrete behaviour hence, the need for such.
f) The environmental impacts and the economic aspects of using LBPA required to be studied.

Acknowledgements

The authors gratefully acknowledge the Petroleum Technology Development Fund (PTDF), Nigeria, for funding the work in collaboration with Universiti Sains Malaysia as part of a PhD research programme.

Declaration

The authors declare no conflict of interest.

REFERENCES

[1] R. H. Faraj, A. A. Mohammed, and K. M. Omer, 'Self-compacting concrete composites modified with nanoparticles: A comprehensive review, analysis and modeling', *Journal of Building Engineering*, vol. 50, p. 104170, Jun. 2022, doi: 10.1016/J.JOBE.2022.104170.

[2] A. M. Neville, *Properties of concrete*. 2011.

[3] C. R. Gagg, 'Cement and concrete as an engineering material: An historic appraisal and case study analysis', *Eng Fail Anal*, vol. 40, pp. 114–140, 2014, doi: 10.1016/J.ENGFAILANAL.2014.02.004.R. Rumman, M. S. Bari, T. Manzur, M. R. Kamal, and M. A. Noor, 'A Durable Concrete Mix Design Approach using Combined Aggregate Gradation Bands and Rice Husk Ash Based Blended Cement', *Journal of Building Engineering*, vol. 30, no. 101303, Jul. 2020, doi: 10.1016/J.JOBE.2020. 101303.

[4] T. Ramlochan, M. Thomas, and K. A. Gruber, 'Effect of metakaolin on alkali-silica reaction in concrete', *Cem Concr Res*, vol. 30, no. 3, pp. 339–344, 2000, doi: 10.1016/S0008-8846(99)00261-6.

[5] M. B. Ahsan and Z. Hossain, 'Supplemental use of rice husk ash (RHA) as a cementitious material in concrete industry', *Constr Build Mater*, vol. 178, pp. 1–9, Jul. 2018, doi: 10.1016/J.CONBUILDMAT.2018.05.101.

[6] D. Chetan and A. Aravindan, 'An experimental investigation on strength characteristics by partial replacement of rice husk ash and Robo sand in concrete', *Mater Today Proc*, vol. 33, pp. 502–507, Jan. 2020, doi: 10.1016/J.MATPR.2020.05.075.

[7] I. S. Agwa, O. M. Omar, B. A. Tayeh, and B. A. Abdelsalam, 'Effects of using rice straw and cotton stalk ashes on the properties of lightweight self-compacting concrete', *Constr Build Mater*, vol. 235, p. 117541, Feb. 2020, doi: 10.1016/J.CONBUILDMAT.2019.117541.

[8] V. M. Malhotra, V. S. Ramachandran, R. F. Feldman, and P. C. A'itcin, 'Condensed silica fume in concrete', *Condensed Silica Fume in Concrete*, pp. 1–221, Jan. 2018, doi: 10.1201/9781351070843/CONDENSED-SILICA-FUME-CONCRETE-MALHOTRA-RAMACHANDRAN-FELDMAN-PIERRE-CLAUDE-A.

[9] M. Thomas, 'Optimizing the use of fly ash in concrete', *Portland Cement Association, Skokie, IL.*, vol. 5420, 2007, Accessed: May 02, 2022. [Online]. Available: https://www.academia.edu/download/57811170/IS548.pdf

[10] E. Özbay, M. Erdemir, and H. I. Durmuş, 'Utilization and efficiency of ground granulated blast furnace slag on concrete properties – A review', *Constr Build Mater*, vol. 105, pp. 423–434, Feb. 2016, doi: 10.1016/J.CONBUILDMAT.2015.12.153.

[11] A. F. Omran, D. M. Etienne, D. Harbec, and A. Tagnit-Hamou, 'Long-term performance of glass-powder concrete in large-scale field applications', *Constr Build Mater*, vol. 135, pp. 43–58, Mar. 2017, doi: 10.1016/J.CONBUILDMAT.2016.12.218.

[12] H. Hamada, A. Alattar, B. Tayeh, F. Yahaya, and A. Adesina, 'Sustainable application of coal bottom ash as fine aggregates in concrete: A comprehensive review', *Case Studies in Construction Materials*, vol. 16, p. e01109, Jun. 2022, doi: 10.1016/J.CSCM.2022.E01109.

[13] B. A. Tayeh, R. Alyousef, H. Alabduljabbar, and A. Alaskar, 'Recycling of rice husk waste for a sustainable concrete: A critical review', *J Clean Prod*, vol. 312, p. 127734, Aug. 2021, doi: 10.1016/J.JCLEPRO.2021.12773 4.

[14] T. Nwofor and S. Sule, 'Stability of groundnut shell ash (GSA)/ordinary Portland cement (OPC) concrete in Nigeria', *Advances in Applied Science Research*, vol. 3, no. 4, pp. 2283–2287, 2012, Accessed: May 02, 2022. [Online]. Available: https://www.researchgate.net/profile/Temple-Nwofor/publication/267727032_Stabiltiy_of_groundnut_shell_GSAordinary_Portland_cement_OPC_concrete_in_Nigeria/links/5523d8d40cf2c815e0733fbb/Stabiltiy-of-groundnut-shell-GSA-ordinary-Portland-cement-OPC-concrete-in-Nigeria.pdf

[15] R. I. Adejoh, 'Investigation of Locus Beans Waste Ash as Partial Replacement for Cement in Concrete Structures', *International Journal of Scientific Research in Education*, vol. 12, no. 1, pp. 144–150, 2019, Accessed: Apr. 29, 2022. [Online]. Available: http://www.ijsre.com.

[16] P. P. Yalley, 'Mechanical and Durability Properties of

Engineered Cementitious Composite Containing High Volume of Pozzolanic admixture', *American Journal of Engineering Research*, vol. 8, no. 4, pp. 229–235, 2019, [Online]. Available: www.ajer.org

[17] C. Ikumapayi, 'Optimisation of Selected Pozzolanic Concrete Mixes for Improved Strength and Durability of Concrete', *Federal University of Technology Akure Information Repository*, 2016, Accessed: May 03, 2022. [Online]. Available: http://196.220.128.81:8080/xmlui/handle/123456789/1599

[18] F. J. Lozano and R. Lozano, 'Assessing the potential sustainability benefits of agricultural residues: Biomass conversion to syngas for energy generation or to chemicals production', *J Clean Prod*, vol. 172, pp. 4162–4169, Jan. 2018, doi: 10.1016/J.JCLEPRO.2017.01.037.

[19] A. Y. Adama, Y. A. Jimoh, and S. S. Kolo, 'Effect of Locust Bean Pod Ash on Compaction Characteristics of Weak Sub Grade Soils', 2013.

[20] S. I. Adedokun and J. R. Oluremi, 'A Review of the Stabilization of Lateritic Soils with Some Agricultural Waste Products', *A NNALS of Faculty Engineering Hunedoara – International Journal of Engineering*, vol. 17, no. 2, pp. 63–74, May 2019, Accessed: May 03, 2022. [Online]. Available:https://www.researchgate.net/publication/334509724_A_REVIEW_OF_THE_STABILIZATION_OF_LATERITIC_SOILS_WITH_SOME_AGRICULTURAL_WASTE_PRODUCTS

[21] O. S. Bello, K. A. Adegoke, O. O. Sarumi, and O. S. Lameed, 'Functionalized locust bean pod (Parkia biglobosa) activated carbon for Rhodamine B dye removal', *Heliyon*, vol. 5, no. 8, p. e02323, Aug. 2019, doi: 10.1016/J.HELIYON.2019.E02323.

[22] H. Duan, Q. Huang, Q. Wang, B. Zhou, and J. Li, 'Hazardous waste generation and management in China: A review', *J Hazard Mater*, vol. 158, no. 2–3, pp. 221–227, Oct. 2008, doi: 10.1016/J.JHAZMAT.2008.01.106.

[23] K. J. Osinubi, A. O. Eberemu, and O. B. Akinmade, 'Evaluation of Strength Characteristics of Tropical Black Clay Treated with Locust Bean Waste Ash', *Geotechnical and Geological Engineering*, vol. 2, no. 34, pp. 635–646, Apr. 2016, doi: 10.1007/S10706-015-9972-7.

[24] S. Samaila and S. Srividya, 'Stabilization of Weak Soils using Locust Bean Waste Ash', *International Journal of Research in Engineering, Science and Technology*, vol. 1, no. 3, pp. 1–6, 2015.

[25] S. M. Auta and A. Kabiru, 'Effect of Locust Bean Pod Epicarp Ash (Lbpea) on the Compressive Strength of Revibrated Concrete', *Construction of Unique Buildings and Structures*, vol. 90, no. 9002, 2020, doi: 10.18720/CUBS.90.2.

[26] S. D. Aliyu, A. Ma'aruf, M. M. Farouq, and S. U. Dawusu, 'Stabilization of Lateritic Soil Using Powdered Locust Bean Pod 'Makuba"', in *International Journal of Engineering & Science Research*, 2018, pp. 249–255. [Online]. Available:https://www.researchgate.net/publication/331963530

[27] A. A. Yisa and Y. Jimoh, 'Production and Classification of Locust Bean Pod Ash (LBPA) as a Pozzolan', *Civil Engineering Portal - Biggest Civil Engineering Information Sharing Website*, 2011, Accessed: Oct. 06, 2022. [Online]. Available: https://www.engineeringcivil.com/production-and-classification-of-locust-bean-pod-ash-lbpa-as-a-pozzolan.html

[28] T. D. Akpenpuun, B. A. Akinyemi, O. Olawale, O. J. Aladegboye, and O. I. Adesina, 'Physical, mechanical and microstructural characteristics of cement-locust bean pod ash mortar blend', *Journal of Applied Sciences and Environmental Management*, vol. 21, no. 4, p. 377, Apr. 2019, doi: 10.4314/jasem.v23i3.1.

[29] A. B. Ochola, J. Abimiku, and P. J. Hirpaya, 'Suitability of Sugarcane Bagasse Ash Locust Beans Waste Ash and Alkaline Activated Metakaolin as a Replacement for Cement in Concrete', *African Scholar Journal of African Sustainable Development (JASD-2)*, vol. 222, pp. 171–180, 2021.

[30] [31] W. Tangchirapat, C. Jaturapitakkul, and P. Chindaprasirt, 'Use of palm oil fuel ash as a supplementary cementitious material for producing high-strength concrete', *Constr Build Mater*, vol. 23, no. 7, pp. 2641–2646, Jul. 2009, doi: 10.1016/J.CONBUILDMAT.2009.01.008.

[31] A. B. Ochola, A. M. Ahmadu, and A. Balarabe Bala, 'Sugarcane Bagasse Ash and Locust Beans Waste Ash as a Replacement for Cement in Concrete', *International Journal of African Sustainable Development*, vol. 16, no. 2, pp. 301–308, Sep. 2021.

[32] J. O. Afolayan, F. O. P. Oriola, and J. E. Sani, 'Experimental Investigation of the Effect of Partial Replacement of Cement in Concrete with Locust Bean Waste Ash', *International Journal of Engineering and Applied Sciences*, vol. 5, no. 12, pp. 42–47, 2018, [Online]. Available: www.ijeas.org

[33] M. E. Ojewumi, A. A. Ayomide, O. M. Obanla, O. O. Awolu, and E. O. Ojewumi, 'Pozzolanic properties of Waste Agricultural Biomass-African Locust Bean Pod Waste', *World Journal of Environmental Biosciences*, vol. 6, no. 3, pp. 1–7, 2014, [Online]. Available: www.environmentaljournals.org

[34] H. Ali, R. I. Babatunde, and B. O. Adejoh, 'Investigation of Locus Beans Waste Ash as Partial Replacement for Cement in Concrete Structures', *International Journal of Advances in Scientific Research and Engineering*, vol. 5, no. 4, pp. 149–153, 2019, doi: 10.31695/IJASRE.2019.33133.

[35] C. Ikumapayi, C. Arum, and P. G. Oguntunde, 'Chloride Ion Penetration Performance of Biogenic Pozzolanic Cement Concrete', *ABUAD Journal of Engineering Research and Development (AJERD)*, vol. 2, no. 2, pp. 68–77, 2019, Accessed: Sep. 29, 2022. [Online]. Available: www.ajerd.abuad.edu.ng/68

[36] C. M. Ikumapayi, 'Chemical and Microstructural Effects of Different Calcinating Temperatures on Selected Pozzolans', *Journal of Materials Science and Chemical Engineering*, vol. 6, no. 12, pp. 16–31, Dec. 2018, doi: 10.4236/MSCE.2018.612002.

[37] O. O. Olubajo, A. Jibril, and O. A. Osha, 'Effect of Locust Bean Pod Ash and Eggshell Ash on the Mortar Compressive and Flexural Strengths of Cement Blends', *Path of Science*, vol. 6, no. 3, pp. 4001–4016, Mar. 2020, doi: 10.22178/pos.56-2.

[38] C. M. Ikumapayi, 'Crystal and microstructure analysis of

Pozzolanic properties of bamboo leaf ash and locust beans pod ash blended cement concrete', *Journal of Applied Sciences and Environmental Management*, vol. 20, no. 4, p. 943, Feb. 2017, doi: 10.4314/jasem.v20i4.6.

[39] ASTM C618, 'Coal Fly Ash and Raw or Calcined Natural Pozzolan', 1994. Accessed: Sep. 29, 2022. [Online]. Available: https://www.appliedtesting.com/standards/astm-c618-coal-fly-ash-and-raw-or-calcined-natural-pozzolan-for-use-in-concrete

[40] A. Y. Adama and Y. A. Jimoh, 'Effect of locust bean pod ash on strength properties of weak soils', *AU Journal of Technology*, vol. 16, no. 1, pp. 27–34, 2012.

[41] O. O. Olu, O. A. Osha, and A. Jibril, 'Setting Times of Portland Cement Blended with Locust Bean Pod and Eggshell Ashes', *American Journal of Chemical Engineering*, vol. 8, no. 5, p. 103, 2020, doi: 10.11648/j.ajche.20200805.11.

[42] S. M. Auta, A. I. Anthony, and A. A. Amadi, 'Flexural Strength of Reinforced and Revibrated Concrete Beams Using Locust Bean Pod Epicarp Ash as Replacement for Cement', *Journal of Civil Engineering, A Publication of NICE*, vol. 12, no. 2, 2020.

[43] E. E. Ndububa and J. O. Uloko, 'Locust Bean Pod Ash (LBPA) as a Pozzolanic Material in Concrete', in *Cement Replacement with Agro-based Pozzolans in Concrete*, 2015.

[44] A. B. Ochola, K. Usman Otaru, and U. Musa, 'Suitability of Locust Beans Waste Ash and Alkaline Activated Rice Husk Ash as Partial Replacement for Cement in Concrete', *Journal of Environmental Design and Construction Mgt*, vol. 19, no. 4, pp. 416–425, Mar. 2021.

[45] I. A. Ja'e, T. A. Sulaiman, and A. A. Abdurrahman, 'Evaluation of Pozzolanic Materials and Their Influence Cement and Workability Retention of Concrete', 2019.

[46] T. D. Akpenpuun, B. Akinyemi, O. Olawale, O. J. Aladegboye, and O. I. Adesina, 'Mechanical and Structural Characteristics of Cement Mortars Blended with Locust Bean Pod Ash', *Agricultural Engineering International: CIGR Journal*, vol. 21, no. 4, pp. 48–55, Dec. 2019, Accessed: May 07, 2023. [Online]. Available: https://cigrjournal.org/index.php/Ejounral/article/view/5525

[47] C. M. Ikumapayi, S. L. Akingbonmire, and O. Oni, 'The Influence of Partial Replacement of Some Selected Pozzolans on the Drying Shrinkage of Concrete', *Guigoz Sci Rev*, no. 511, pp. 189–197, Nov. 2019, doi: 10.32861/sr.511.189.197.

[48] C. M. Ikumapayi and S. L. Akingbomire, 'Effects of Bamboo Leaf and Locust Beans Pod Ashes on Autogenous Shrinkage Strain and Compressive Strength of Mortar', *FUTA Journal of Engineering and Engineering Technology*, vol. 12, no. 1, pp. 49–53, 2018, Accessed: May 11, 2022. [Online]. Available:https://www.futajeet.com/index.php/jeet/article/view/67

[49] A. M. Neville, *Properties of Concrete*. Prentice Hall, 2012. Accessed: Sep. 29, 2022. [Online]. Available: https://books.google.com/books/about/Properties_of_Concrete_PDF_eBook.html?id=WW1wUvwQ0sUC

[50] A. A. Akindahunsi and H. C. Uzoegbo, 'Strength and Durability Properties of Concrete with Starch Admixture', *Int J Concr Struct Mater*, vol. 9, no. 3, pp. 323–335, Sep. 2015, doi: 10.1007/S40069-015-0103-X/FIGURES/22.