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# EFFECTS OF LOCUST BEAN POD (*PARKIA BIGLOBOSA*) EXTRACT ON WORKABILITY AND STRENGTH OF CONCRETE

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## ABSTRACT

**Purpose:** Predominantly in the northern part of Ghana and other neighbouring West African countries, the Locust Bean Pod Extract (LBPE), known for its adhesive and cohesive properties, has enjoyed high patronage in its incorporation in various traditional construction formulations, especially in the production of clay floor tiles and bricks for some time now. To justify the material's continual use, this paper explored the impact of the LBPE on the properties of fresh and hardened concrete.
**Design/Methodology/Approach:** LBPE was obtained by soaking the pods in 10g per litre of water for different extraction periods. Based on LBPE replacement percentages and soaking durations, 469 concrete cubes were formed from 9 different concrete mixes. The slumps for the various mixes and the strength of hardened concrete were tested after curing durations of 7 days to 28 days.
**Findings:** The experimental results revealed that LBPE enhanced the strength of concrete and gave it more workable mixes than concrete made with ordinary water. X-ray Diffraction (XRD) analysis on the control indicates the presence of Oligoclase, whilst the LBPE samples indicate the presence of Albite. Scanning electron microscope (SEM) analysis revealed the differences in element composition of both the control and LBPE samples. LBPE extraction at 4 days and 75% LBPE replacement of water achieved 54.67% more 28-day strength and over 21% more workability than the control. Fourier Transform Infrared results indicate that tannins are the primary functional element in LBPE.
**Research Limitations:** This study established that replacing water with LBPE significantly improves the workability and strength of concrete. The extraction at 4 days and 75% water replacement with LBPE yielded optimum results.
**Practical implications:** This study provides a sustainable and low-cost solution to the mutually exclusive problem of increasing concrete workability and strength.
**Social Implication**: This study will assist practising engineers in dealing with the issue of artisans increasing the water-cement ratio of mixes to obtain workable mixes, which results in weak concrete strength and subsequent failure of concrete structures
**Originality/ Value:** This original experimental laboratory study addresses the problem of artisans using too much water to mix concrete to ensure workable mixes.
***Keywords**: Locust bean pod. replacement. strength. water-cement ratio. workability*

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## INTRODUCTION

The recent rampant failure of buildings in the Ghana construction industry can be attributed to the inability to implement building design specifications, especially regarding the cement-water ratio, a significant determinant of fresh concrete workability and hardened concrete strength. An increase in the cement-water ratio tends to increase the workability of fresh concrete (ElNemr, 2019). The reverse is valid for the strength of hardened concrete. Strength reduces with an increase in the water-cement ratio (Eme & Nwaobakata, 2019; Salain, 2021; Singh et al., 2015).

Failure to maintain the designer specifications leads to houses developing cracks that collapse entirely, rendering the inhabitants homeless. Consequently, additional costs to clients and engineers are constantly rising when repairing on-site. The price of construction works (concrete) has also correspondingly increased. In many developing countries, most of the population finds the cost problematic or virtually unaffordable (Aguwa, 2009). Quality concrete works are expensive. Coupled with the low strength of concrete commercially produced by artisans using hand turning necessitates the need for an alternative way of maintaining both fresh concrete workability and subsequently hardened concrete strength on a construction site (Aguwa, 2010). Concrete works are created by combining chippings, sand, cement, and a reasonable amount of water in a designed workable mix proportion, with or without the presence of additives, aiming at the desired strength required. The final product is cured for days to achieve the needed strength. The mixture's binding agent, cement, acquires strength in adequate water for hydration. Therefore, the water-cement ratio must be adequately followed to meet the required or designed strength specifications.

The locust bean extract has been used as a source of binding agent for local construction activities in the northern part of Ghana and other West African countries (Aguwa et al., 2016; Aguwa & Okafor, 2012). Among the people of the northern parts of West African countries, the locust bean pod is boiled or soaked in water to obtain a reddish-brown coloured extract. In lateritic soils, the extract is primarily utilised as a binding agent to construct durable floor finishes for rooms as well as strengthen walls (Oyelaran et al., 2015; Umar, 2019). However, the science behind the locust bean pod's workings as a binder and its effects on concrete have not been fully understood. This paper sought to investigate the impact of locust bean pod extract on fresh and hardened concrete characteristics.

## LITERATURE REVIEW

### The African Locust Bean Tree and Pods

The African locust bean (*Parkia biglobosa*) is a perennial leguminous tree crop commonly grown in the tropics and savannah areas (Campbell-Platt, 1980; HOPKINS, 1983). The African locust bean tree can be found in Ghana, Nigeria, Uganda and Senegal. In Ghana, it is commonly found

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in the northern regions and other parts of the country, such as Kintampo, Techiman and some parts of the Eastern region, especially Afram Plains. The trees bear fruits with seeds in them. According to Tengan et al. (2011), the fruits comprise 39.72% husk, 23.31% seed and 25.08% pulp. The pulp and the seeds are used for various purposes ranging from food, due to its high nutritional value, to medicinal. The husk is a waste material which is mostly discarded. The husks or the pods were used in this study.

### Chemical composition of aqueous extract of Locust Beam Pod (LBPE)

Abagale et al. (2013) a study on the chemical analysis of the aqueous extract of P. biglobosa used both ethanol and water as solvents for the extraction process and concluded that water was the best solvent for the extraction process. The husk of the locust bean contains tannins and polyphenols, flavonoids, alkaloids and saponins, anthraquinones and glycosides (Abagale et al., 2013; Okewale & Adedokun, 2022).

Auta et al. (2016) posited that LBPE contains all the major oxides present in ordinary Portland cement and can be regarded as a suitable binder or pozzolana. Essentially, the extract contains 49.99% silicon dioxide ($SiO_2$), 3.294% Calcium oxide (CaO), 18.966% Aluminium oxide ($Al_2O_3$) and 6.342% Iron (III) oxide ($Fe_2O_3$).

### Previous Experimental Works on the Uses of Locust Bean Pod Ash (LBPA) and Locust Bean Pod Extract (LBPE)

Several studies have been conducted on using LBPA as pozzolanic material in concrete. Many of these studies reported improved results when LBPA is used as a pozzolanic material.

Auta & Kabir (2020) studied the effect of locust bean pod epicarp ash (LBPA) on the compressive strength of re-vibrated concrete. They obtained LBPA by controlled locust bean pod epicarp incineration in an enclosed furnace. Chemical analysis of the ash produced gave 77.81% as the sum of $SiO_2$, $Al_2O_3$ and $Fe_2O_3$ content, indicating a very good pozzolana by ASTM C – 618 standards. In their work, concrete cubes were produced with varying percentages (0, 5, 10, 15, 20, 25 and 30%) of cement replacement with LBPA and tested after 7, 14 and 28 days of curing. In terms of early strength development (7 days of curing) and for 60-minute intervals of re-vibration, the control (0% of LBPA) gave higher values of 25.29 $N/mm^2$ while the optimum LBPA replacement (5%) gave 21.11 $N/mm^2$. On the other hand, for late strength development (28 days of curing) and 60-minute intervals of re-vibration, the control gave 22.28 N/mm2, whilst 5% replacement by LBPA gave 28.44 $N/mm^2$. This clearly shows that 5% replacement by LBPA performs better than using only ordinary Portland cement. However, other replacement values show significantly lower values as compared to the control.

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In another study by Auta et al. (2016), the flexural strength of concrete produced with partial replacement by Locust Bean Pod Extract (LBPE) was investigated. They observed that the LBPE is a suitable binder or pozzolana containing all the significant oxides in ordinary Portland cement. Essentially, the extract contains 49.99% silicon dioxide ($SiO_2$), 3.294% Calcium oxide (CaO), 18.966% Aluminium oxide ($Al_2O_3$) and 6.342% Iron (III) oxide ($Fe_2O_3$). They reported increased flexural strength over the control when LBPE replaced water in all the replacements (5%, 10% and 15%). The optimum result of about a 6% increase in flexural strength was observed for the 10% replacement of water with LBPE.

Yet another research work carried out by Auta et al. (2020) on the effect of re-vibration on the flexural strength of concrete, using locust bean pod epicarp ash as a partial replacement for cement provided interesting results. The LBPA used in this test was analysed chemically using an X-ray fluorescent (XRF) test, and the results indicate the LBPA contained contains 49.054% silicon dioxide ($SiO_2$), 11.125% Calcium oxide (CaO), 12.046% Aluminium oxide ($Al_2O_3$) and 8.925% Iron (III) oxide ($Fe_2O_3$). Thus, the LBPA for this study was classified as a class F pozzolanic material according to ASTM C 618-9. Their flexural test results show that replacing cement with LBPA at an optimum replacement value of 5% does not significantly affect the flexural strength when concrete is re-vibrated.

Aguwa & Okafor (2012) investigated the use of locust bean pod extract as a binder for producing laterite blocks for buildings. Particle size distribution tests on the lateritic material revealed that the material could be classified as well-graded gravel, with about 14% passing through the 75µm sieve size. Lateritic blocks were moulded by ramming with a 2.5 kg hammer falling from a height of 300 mm with only water for mixing as the control and with only locust bean pod extract at varying concentrations (0.04 kg/l, 0.06 kg/l, 0.08 kg/l and 0.10 kg/l) for mixing the test specimens. Both the blocks moulded with the extract and the control were cured under atmospheric conditions and tested after 7, 14, 21 and 28 days. They observed that compressive strength tests on the blocks revealed that the test specimens produced higher compressive strength values than the control. Generally, the higher the concentration of the extract, the higher the compressive strength of the block. The highest extract concentration of 0.10 kg/l produced the highest compressive strength, 78.57% of the control.

Further studies were conducted by Aguwa et al. (2016) on the effectiveness of locust bean pod solution (LBPS) in producing sandcrete blocks for buildings. In this study, various extract concentrations were prepared by soaking various weights of the husks in water for 24 hours. The various concentrations of the extracts were used to prepare sandcrete blocks. In addition, a known concentration of 50 g/l was used to prepare sandcrete blocks in which the weight of cement was reduced by 0, 5, 10, 15, 20, 25, 30, 35 and 40%, respectively. The blocks were cured and tested at 7, 14, 21 and 28 days. The effect of the duration of soaking was also investigated by soaking the same 50 g/l weight of husk for 1, 2, 3, 4, 5, 6, 7, 8, 9 and 10 days, respectively and using the

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extracts to mould sandcrete blocks which were crushed for compressive strength after 28 days of curing. The results indicated that the compressive strength of sandcrete blocks increases with increasing extract concentration and that the extracts can be used to reduce the cement content by as much as 25% without adversely affecting the compressive strength of the sandcrete blocks. They also reasoned that soaking the pods for more than 24 hours is not necessary because the compressive strength of blocks tends to decrease with LBPE extraction periods greater than 24 hours.

## MATERIALS AND METHODS

### Research Strategy

This study investigated the properties of fresh and hardened concrete made with LBPE as a substitute for water. The procedure adopted was to use a water-to-cement ratio of 0.65 in a 1:2:4 mix ratio and hand mixing of concrete to replicate what is usually practised by artisans in the field. The fresh concrete was compacted using a vibratory plate after placing concrete cubic moulds with dimensions of 150 mm on each side. Different concrete cubes were made by replacing water with LBPE at varying percentages whilst keeping the overall water-cement ratio and other components of the concrete mix constant. In all, 469 concrete cubes were cast and tested. Fresh concrete's workability was determined by applying the slump test, per ASTM C143 (2015), while the compressive strength of the concrete produced was determined by cube crushing after various curing durations following BS EN 12390-3 (2009). An X-ray diffraction (XRD) examination was carried out on the concrete samples to determine the significant rock-forming minerals within the concrete. SEM analysis with backscatter diffraction was employed to ascertain the different constituent elements in the concrete samples. The functional groups within LBPE were also analysed using Fourier Transform Infrared (FTIR) Spectroscopy. X-ray Fluorescence (XRF) examination was also carried out on the LBPE to determine the elements and oxides within the extract.

### Extraction Method

Tap water was used for the extraction process. The concentration of the extract was 10 grams of pounded pods in one litre of water. The extracts were appraised into eight different categories based on the extraction periods. Table 1 details the extraction process for each sample, and Figure 1 illustrates sample extraction.

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*Table 1: Details of the Extraction Process*

| Samples | Extraction Period Soaking Duration(day) | Amount of Locust Bean Pod(kg) | Volume of Tap Water Added(litre) |
|---|---|---|---|
| **Sample 1** | 1 | 0.35 | 35 |
| **Sample 2** | 2 | 0.35 | 35 |
| **Sample 3** | 3 | 0.35 | 35 |
| **Sample 4** | 4 | 0.35 | 35 |
| **Sample 5** | 7 | 0.70 | 70 |
| **Sample 6** | 14 | 0.70 | 70 |
| **Sample 7** | 21 | 0.70 | 70 |
| **Sample 8** | 21 | 0.70 | 70 |

*Figure 1: Pounded and Soaked Locust Bean Pods During the Extraction Process*

## Materials and Design Mix

Materials used:
GHACEM (Super Cool) *Ordinary Portland Cement (OPC)* with grade 32.5N classified as CEMII / B-L 32.5N Portland Limestone Cement.
*Fine Aggregate:* Sand, essentially within the 9.5 mm to 0.075 mm size range, was used to form all the concrete cubes. The index property tests used a weight of 4000g of fine aggregate.
*Coarse Aggregate:* Coarse aggregate grading used 60mm to 10mm sieve sizes. Gradation tests were carried out on 6000g of coarse aggregates used in producing the cubes.
*Portable Water for Mixing:* The concrete for this research work was mixed using portable water.
*Locust Bean Pod:* The locust bean pods for the experiment were taken from Wa in the Upper West region of Ghana.

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### Tools and Equipment

Tools and equipment used included sacks, scales, buckets, soil sieves, 100-litre containers, slump cone, tamping rod, trowel, shovel, concrete mixing container, tape measure, concrete moulds, air compressor for removing cubes and riffle box.

### Different Percentages of LBPE

During the investigation, different percentages of the locust bean pod extracts were applied to ascertain the percentage of LBPE replacement that will give concrete higher workability and compressive strength.

### Preparation of Concrete Cubes

For this investigation, 150 mm-size concrete cubes were produced. Some variables were constant in preparing the concrete cubes, including aggregate sizes, the mix ratio, and cement content (amount, grade, and brand). These constituents were batched by weight to obtain the suitable proportions of concrete ingredients. A 1:2:4 mix ratio (cement, fine aggregate, and coarse aggregate) was used for the investigation, with a corresponding water-cement ratio of 0.65. This is to replicate the consistency and strength range of concrete produced and placed by artisans in the construction industry in Ghana. Sixty-seven different mixes were made, giving 469 cubes for this research. The cubes were cured for 7, 14, 21, and 28 days before crushing.

### Aggregate Gradation

The aggregates used in the study were obtained from the Civil Engineering Laboratory of Sunyani Technical University in Sunyani, Bono region of Ghana. The aggregates were dried at room temperature before the concrete cubes were cast. Gradation analysis was performed on coarse and fine aggregates, which were subsequently classified according to the Unified System of Soil Classification (USCS).

## RESULTS AND DISCUSSION

### Observation After the Extraction Period

The extracts were categorised into eight (8) different sections based on their extraction period. For extracts 1, 2, 3, and 4, 35 litres of water were used to soak each 350g of locust bean pod. After 1, 2, 3, and 4 days, the pods were removed, respectively, and it was observed that the volume of water had been reduced from 35 litres to about 30 litres for each of the extracts.

Extract samples 5, 6, 7, and 8 had a similar observation as the initial extraction. However, in extract samples, 5, 6, 7 and 8, 700 g each of locust bean pods was added to 70 litres of water and observed for 1, 2, 3 and 4 weeks, respectively. It was observed that the volume of water has reduced from

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70 litres to about 65 litres. A possible reason for the reduction in volume could be evaporation and the water absorption of locust bean pods since the husks were dried before soaking and, therefore, have the potential to absorb the water.

## Classification of Aggregates Using the USCS

*Fine Aggregates:* Figure 2 is a chart that shows the distribution of particle sizes for the fine aggregates used for the concrete. The grading characteristics show that the soil is poorly graded sand (SP) based on the USCS.

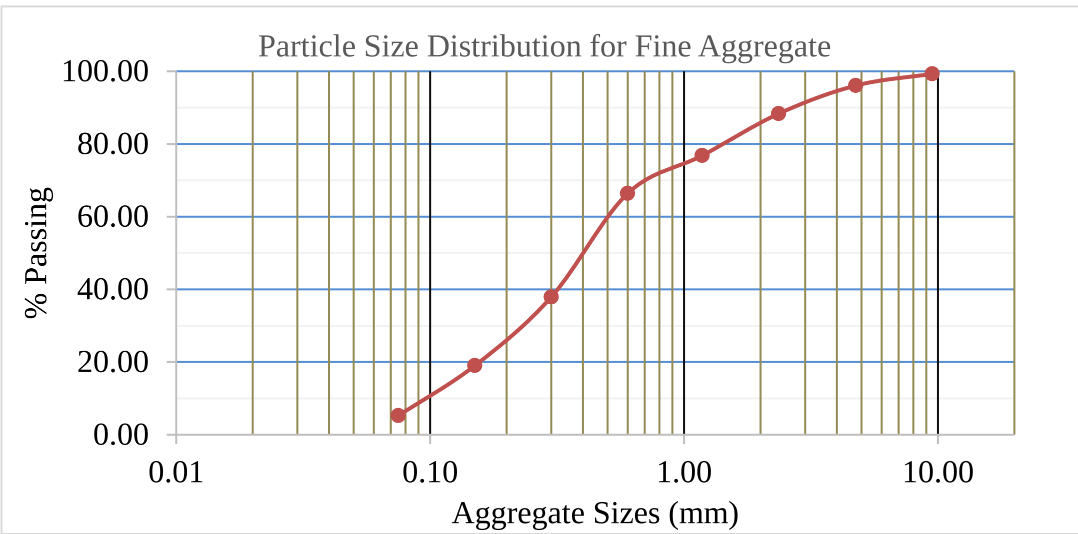


*Figure 2: Gradation Curve for Fine Aggregate*

*Coarse Aggregates:* Figure 3 shows the particle size distribution graph for the coarse aggregates used for the concrete. The grading characteristics reveal poorly graded gravel (GP) based on the USCS.

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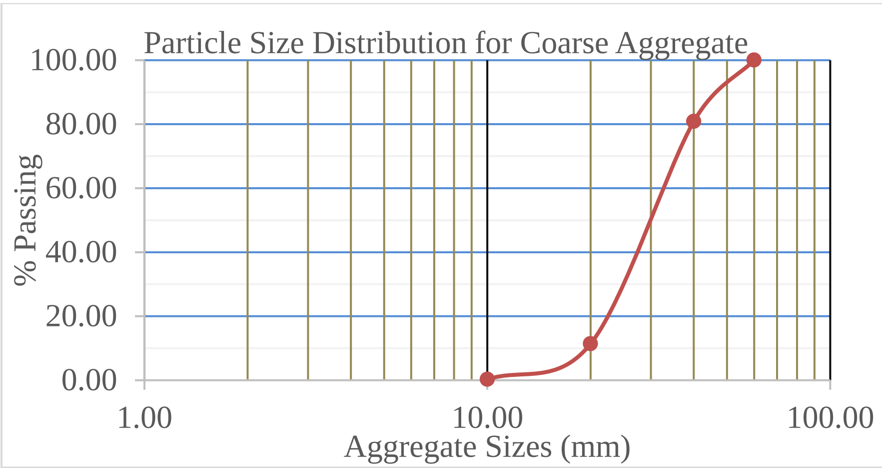


*Figure 3: Particle size Distribution Curve for Coarse Aggregate*

## Chemical Composition of LBPE

Figure 4 shows a spectrum graph of FTIR analysis of LBPE, while Table 2 gives the significant elements and oxides within the LBPE using XRF analysis. The observed peak at 3326.19cm$^{-1}$ falls within the 3400 – 3200 band for OH stretching tannins and catechol tannins (Zhu et al., 2004; Muruganathan et al., 2005; Fernández & Agosin, 2007; Ricci et al., 2015). The peak of 2115.40cm$^{-1}$ corresponds to H – O – H bending free water as well as $CH_3$ and $CH_2$ stretching, that is, the alkyne group (Pantoja-Castro & González-Rodríguez, 2011; Pardeshi et al., 2013; Ping et al., 2012; Ricci et al., 2015). The peak of 1634.61cm$^{-1}$ also corresponds to the C=C stretching of the alkene group (Chen et al., 2010; Jensen et al., 2008; Ricci et al., 2015). The results indicate that the extract contains tannins, which can undergo a series of chelation reactions to form complexes (Slabbert, 1992).

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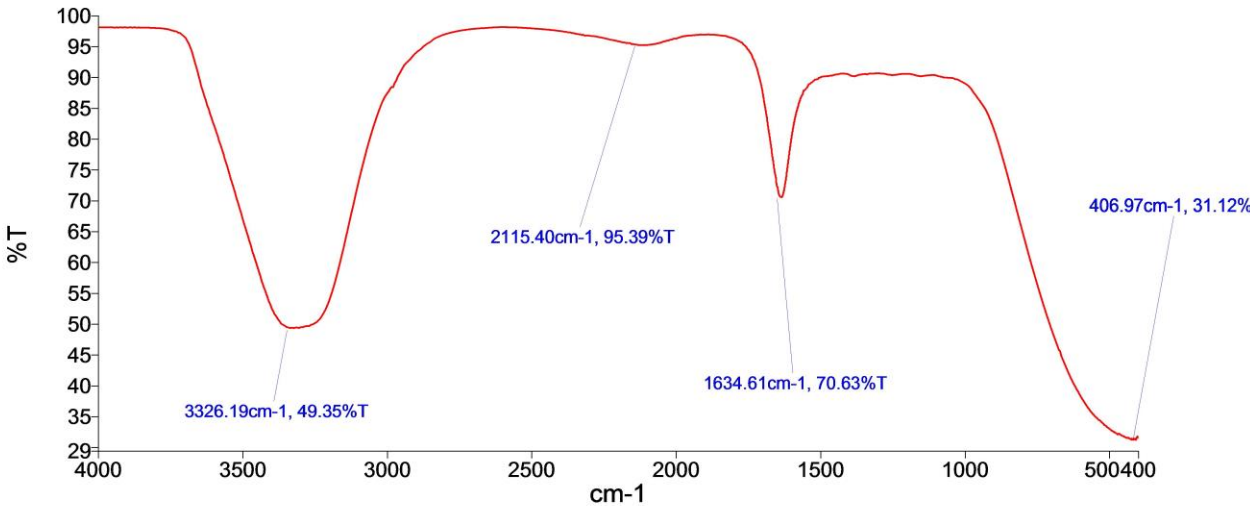


*Figure 4: FTIR Spectrum Graph of LBPE*

The XRF analysis results from Table 2 indicated the presence of Magnesium, Potassium Lead, Calcium, Silicon and Aluminium as significant elements in descending order of parts per million (ppm). The oxides of the same elements were identified in the elemental analysis in the same order according to percentage by weight in the LBPE. Other elements and oxides present, but less than 60 ppm for elements and less than 0.006% by weight for oxides, are regarded as trace elements and are not reported here.

*Table 2: Major Oxides and Elements of LBPE from XRF Analysis*

| **OXIDES** | | **ELEMENTS** | |
|---|---|---|---|
| **Unit** | wt.% | Unit | ppm |
| **MgO** | 0.5336 | Mg | 3218 |
| **Al2O3** | 0.0697 | Al | 369 |
| **SiO2** | 0.0888 | Si | 415 |
| **P2O5** | 0.1638 | P | 715 |
| **K2O5** | 0.1590 | K | 786 |
| **K2O** | 0.0947 | Ca | 890 |
| **CaO** | 0.1245 | | |

## Results from Slump Tests

Table 3 summarises the findings of the slump test carried out on the fresh concrete. The average slump value for the control was 78mm, while the slump values for LBPE replacement varied

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widely, from a low of 20mm for 100% LBPE replacement at 3 weeks soaking duration to a high of 245mm for 25% LBPE replacement at 1-day duration soaking.

*Table 3: Slump Test for the Various Soaking Days and Replacement with LBPE (mm)*

| LBPE Replacement (%) | LBPE Soaking Duration | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 day | 2 days | 3 days | 4 days | 1 week | 2 weeks | 3 weeks | 4 weeks |
| **100** | 89 | 80 | 95 | 111 | 96 | 110 | 20 | 54 |
| **75** | 124 | 130 | 96 | 95 | 95 | 75 | 27 | 71 |
| **50** | 115 | 144 | 96 | 130 | 105 | 160 | 45 | 56 |
| **25** | 245 | 139 | 120 | 102 | 104 | 165 | 74 | 50 |
| **20** | 110 | 122 | 146 | 112 | 125 | 167 | 75 | 100 |
| **15** | 130 | 118 | 119 | 100 | 134 | 100 | 42 | 95 |
| **10** | 131 | 116 | 120 | 102 | 136 | 75 | 77 | 88 |
| **5** | 120 | 122 | 123 | 115 | 137 | 100 | 47 | 110 |
| **0** | 78 | | | | | | | |

The slump values for all LBPE replacements at 3 weeks duration of soaking were all less than the average slump value for the control, indicating that at 3 weeks duration of soaking, all LBPE replacements produced poorly workable mixes than the control. For the 2-week duration of soaking, 75% and 10% LBPE replacement have less workable mixes than the control, while for the 4-week duration of soaking, 25% to 100% LBPE replacement offers less workable mixes.

All LBPE replacement mixes at 1-day to 1-week soaking have higher slump values than the average slump value for the control, suggesting that these mixes are more workable than the control mix. The LBPE replacement with water generally gives a higher slump in fresh concrete and, therefore, offers highly workable mixes for a 1-day to 1-week soaking duration.

Polymers such as tannins and resins are known superplasticisers which enhance the workability of concrete without the addition of more water (Olivia et al., 2018; Peschard et al., 2004, 2006; Pizzi, 2008) . Also, the well-known retarding effects of carbohydrates are virtually absent in the case of tannins and tannin extracts (Pizzi, 2008). According to Abagale et al. (2013), tannins constitute a significant component of LBPE. Thus, the higher slump values for LBPE samples compared to the control sample can be ascribed to tannins in the LBPE, which serve as lubricants to fluidify the concrete.

As noted in the results, soaking for more than 1 week gave lower values than soaking one week

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and below. These could be attributed to fermentation during the extraction process for a long duration. Some bacteria could reduce the tannin and other phenolic compounds' content during fermentation (Shang et al., 2019; Šalić & Šamec, 2022; Tian et al., 2023). Thus, the reduction in tannin content due to fermentation could result from lower slump values at a longer duration of the extraction process.

## Compressive Strength

Figures 4 to 11 illustrate concrete cube crushing test results. The results show that the compressive strength of the concrete cubes with LBPE at various percentages of replacement and curing was higher than that of the control (0% LBPE) for all soaking durations up to one week. Mixed results were obtained for soaking durations of 2 weeks and above.

As seen in Figure 5 for the one-day extract, the 20% LBPE gives the highest strength of 18.24N/mm$^2$ after 28 days of curing. This represents a 33.14% increment over the control strength of 13.70N/mm$^2$.

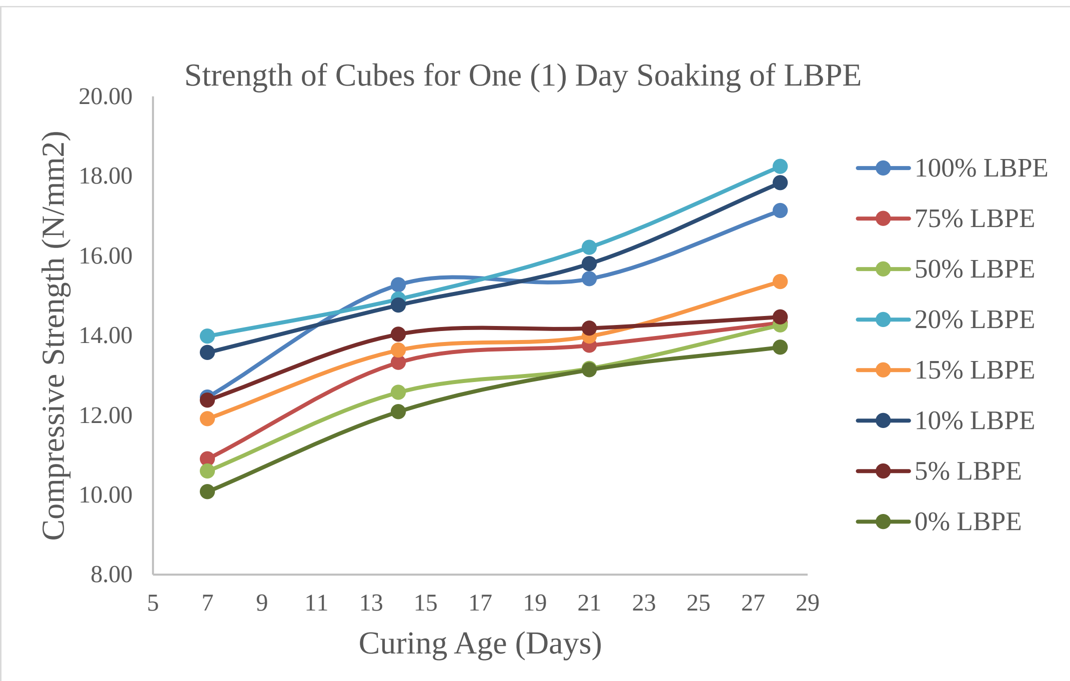


*Figure 5: Compressive Strength of Cubes After One Day Soaking Duration of LBPE*

As demonstrated in Figure 6, the highest 28-day strength for the 2-day extract was 18.63N/mm2 for the 5% LBPE. From Figure 7, the maximum 28-day strength for the 3-day extract is

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16.34N/mm2 for the 100% LBPE. These values correspond to 35.99% and 19.27% increments over the control for the 2-day and 3-day extracts, respectively, as shown in Figures 5 and 6.

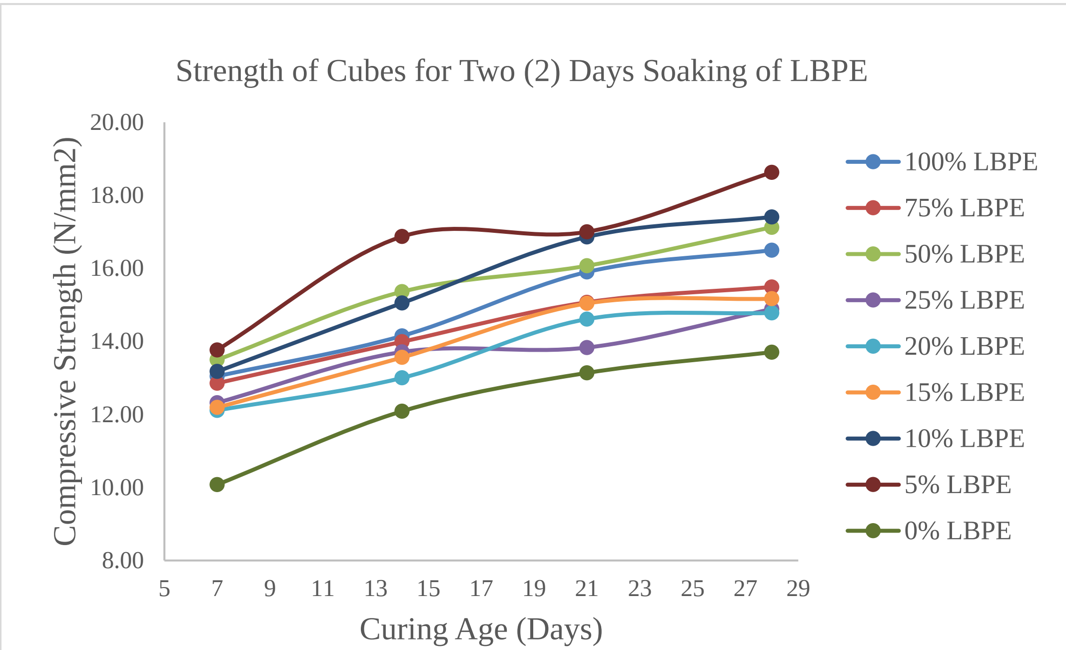


*Figure 6: Compressive Strength of Cubes After Two Days Soaking Duration of LBPE*

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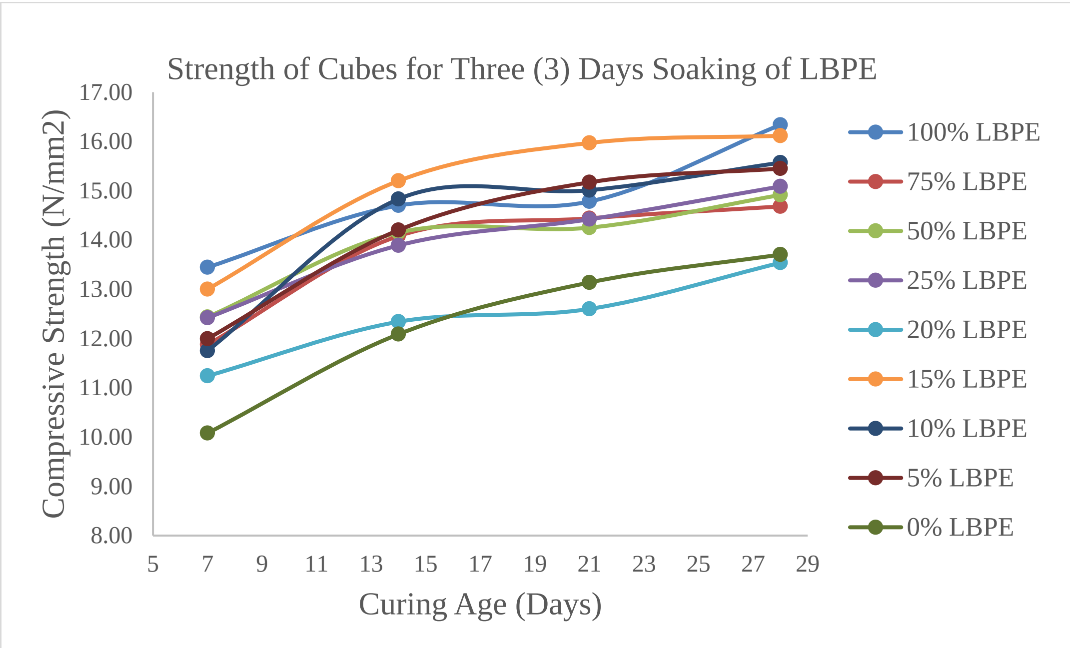


*Figure 7: Compressive Strength of Cubes After Three Days Soaking Duration of LBPE*

The highest 28-day strength of 21.19N/mm$^2$ for the 4-day extract was recorded at 75% LBPE, while that for the 1-week extract was 17.73N/mm2 at 25% LBPE. These correspond to 54.67% and 29.42% increments in strength over the control for the 4-day and 1-week extracts, respectively, as illustrated in Figures 8 and 9.

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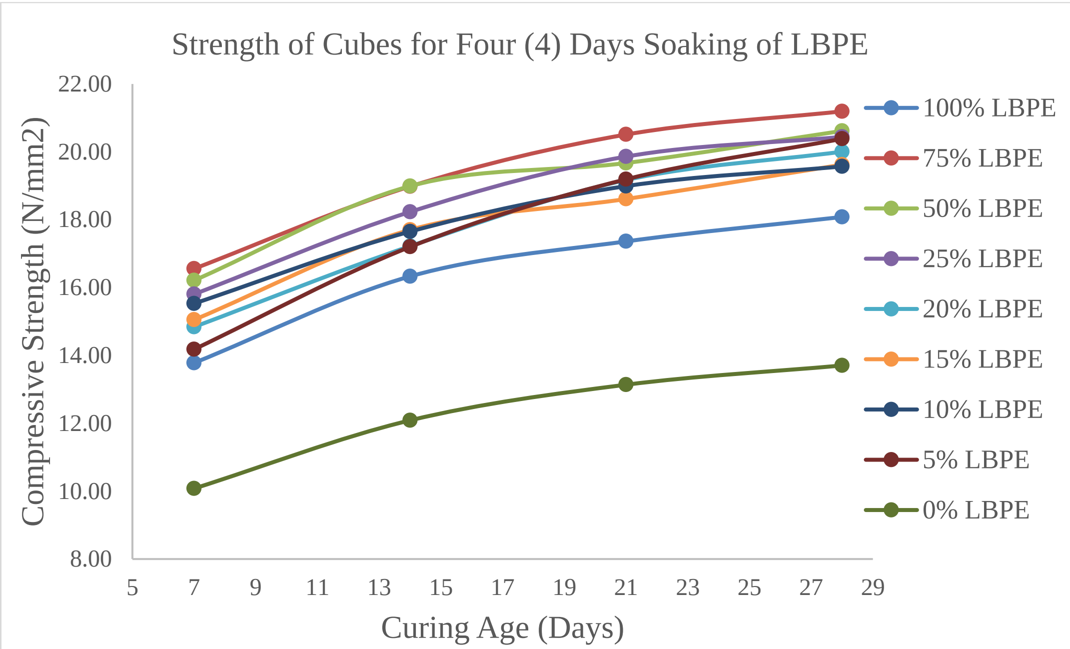


*Figure 8: Compressive Strength of Cubes After Four Days Soaking Duration of LBPE*

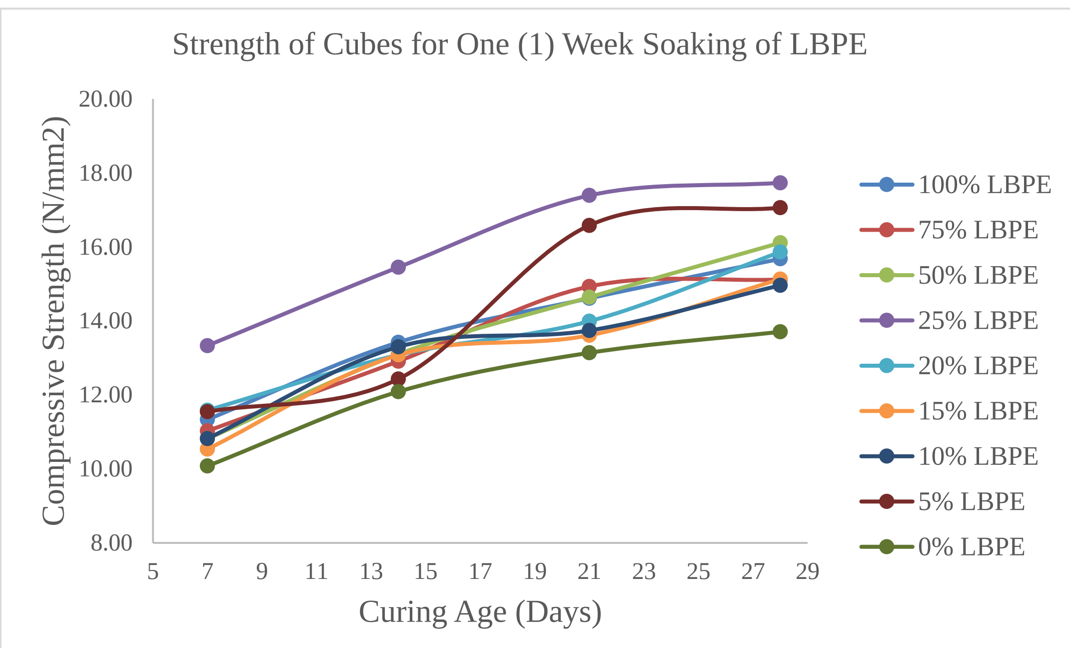


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*Figure 9: Compressive Strength of Cubes After One Week Soaking Duration of LBPE*

For the 2-week, 3-week and 4-week extracts, the highest 28-day strengths recorded were 16.29 N/mm$^2$ for 10% LBPE, 14.17 N/mm$^2$ for 100% LBPE and 16.36 N/mm$^2$ for 25% LBPE respectively. These values depict 18.91%, 3.43% and 19.42% increments in strength over the control for the 2-week, 3-week and 4-week extracts, respectively, as illustrated in figures 10, 11 and 12.

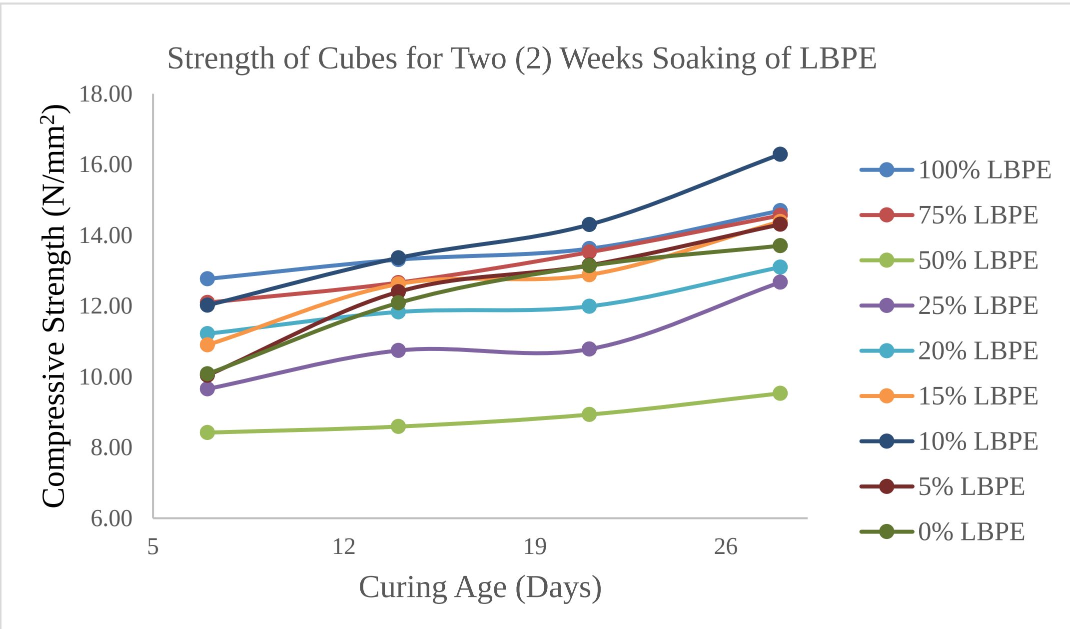


*Figure 10: Compressive Strength of Cubes with Two Weeks LBPE Soaking Duration*

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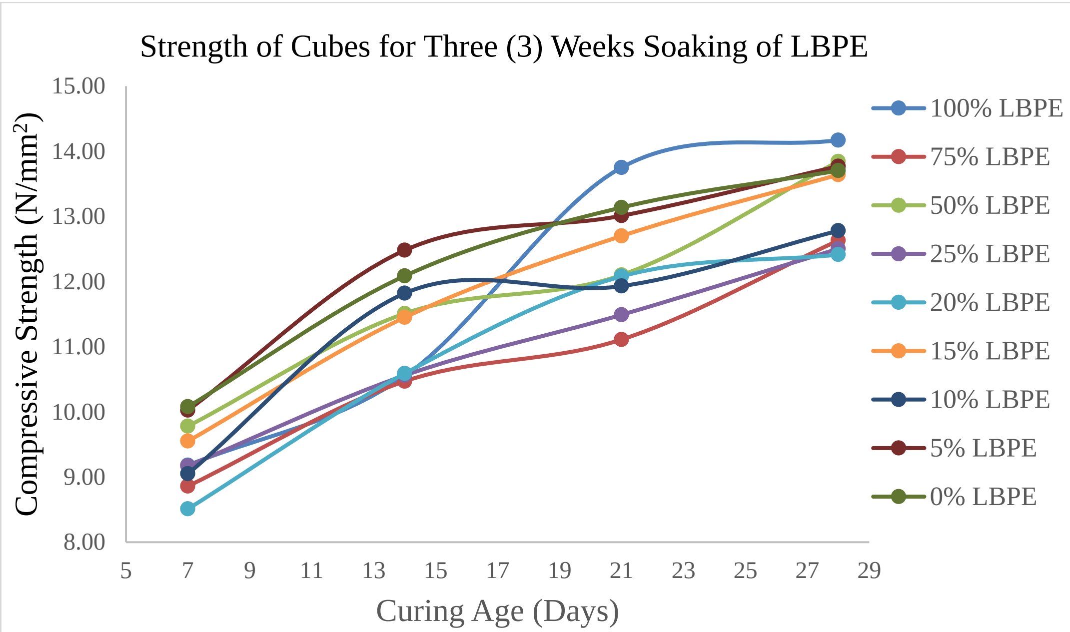


*Figure 11: Compressive Strength of Cubes with Three Weeks LBPE Soaking Duration*

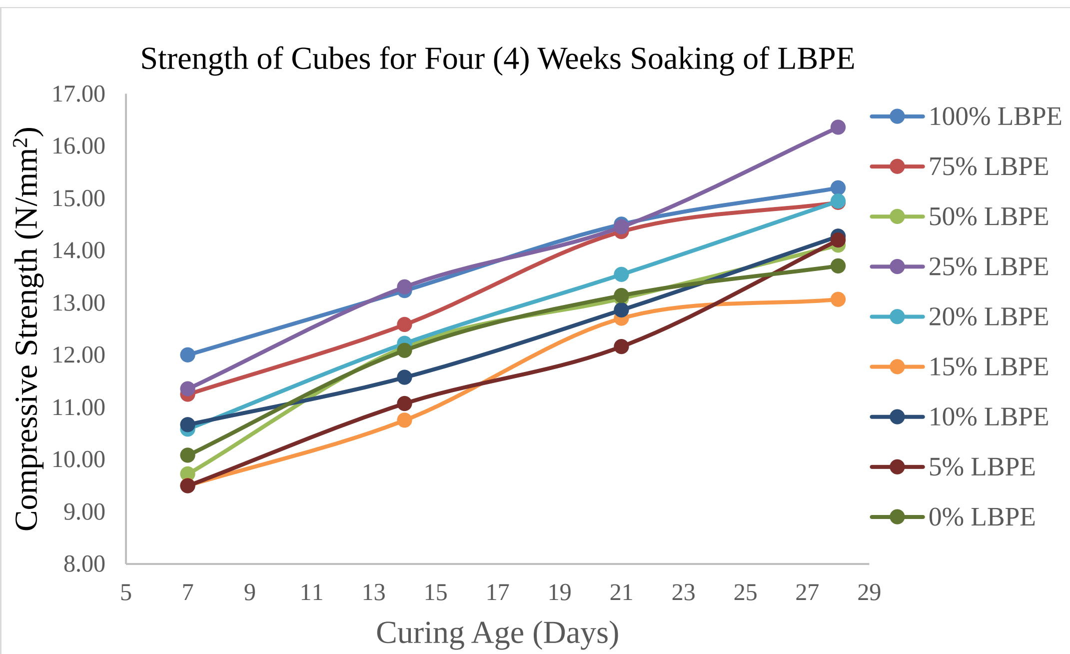


*Figure 12: Compressive Strength of Cubes with Four Weeks LBPE Soaking Duration*

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Concrete cubes for four days of soaking for the extract and 28 days of curing at 75% LBPE replacement attained the highest strength compared to the remaining samples concerning the locust bean pod's soaking days and concrete days. Again, strength results from all concrete cubes with LBPE replacing water either entirely or partially exhibit higher strengths than the control. This means that for concrete works, the maximum potential of the LBPE can be obtained by soaking it for four days. Furthermore, the optimum replacement of water with LBPE occurs at 75% replacement of water with LBPE, as shown in Figure 8.

From the studies of Abagale et al. (2013) and Okewale & Adedokun (2022), LBPE contains tannins and flavonoids. Thus, LBPE could be regarded as a bio-based polymer. FTIR analysis has confirmed the presence of tannins in the LBPE (figure 4). Polymers have been used for the past 30 years to enhance the properties of cement, according to Momtazi et al. (2015) and Pizzi (2008). These are called polymer concretes and have the advantages of improved strength and durability, among others (Momtazi et al., 2015; Olivia et al., 2018; Pizzi, 2008). This could account for the strength increases seen in the results indicated above.

As noted in the results, soaking for more than 1 week gave lower values than soaking for one week and below. These could be attributed to fermentation and the breakdown of tannins and volatile components in the extracts during the long extraction process. Some bacteria could reduce the tannin and other phenolic compounds' content during fermentation. (Shang et al., 2019), (Šalić & Šamec, 2022) and (Tian et al., 2023). Thus, the reduction in tannin content due to fermentation could result in lower strength values at a longer duration of the extraction process.

## Chemical Composition of the Concrete Cubes

### *X-Ray Diffraction (XRD)*

XRD examination of the control concrete cubes indicates the presence of Quartz and Oligoclase as the significant constituent mineral compounds. Minor constituent mineral compounds detected were Portlandite, Calcite, and Muscovite, with Rutile, Gibbsite, and Levyne-Ca as trace elements, as shown in Figure 13.

XRD analysis of the LBPE concrete cubes indicates the presence of Quartz, Albite, Portlandite, and Calcite as the significant constituent mineral compounds. Muscovite and rutile were minor constituent minerals, while Gibbsite and Levyne-Ca were detected as trace elements, as shown in Figure 14.

All mineral compounds in the LBPE concrete cubes were at higher concentrations than in the control sample. However, Albite was utterly absent, replaced by oligoclase. The high percentages of Portlandite observed in the samples could be attributed to the early age (7 days) of the concrete cubes analysed.

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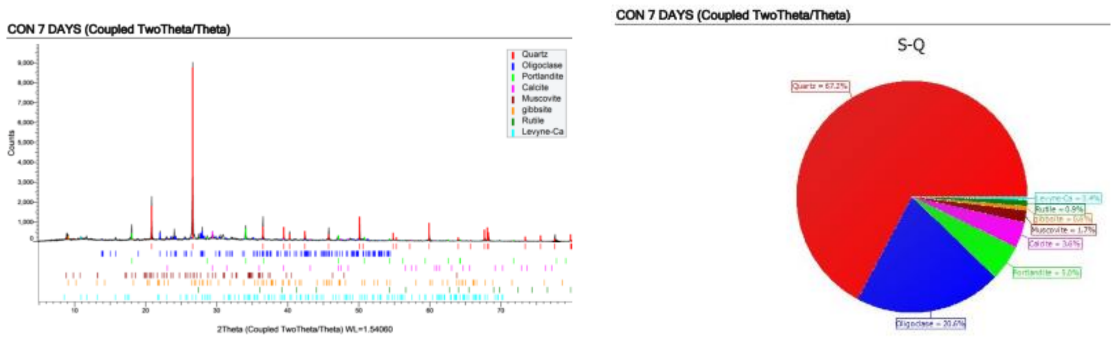


*Figure 13: XRD of Control Concrete Cubes at 7 days*

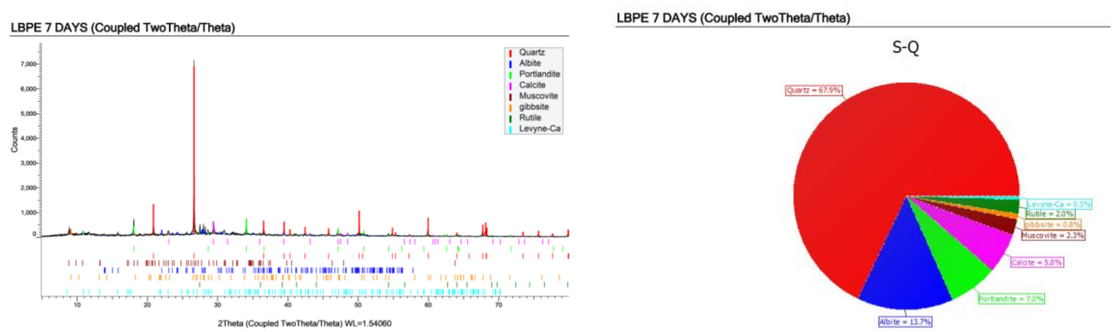


*Figure 14: XRD of LBPE Concrete Cubes at 7 days*

*Scanning electron microscopy (SEM)*

Figures 15 and 16 show how scanning electron microscopy with backscatter diffraction was used to determine the elements within the concrete cubes.

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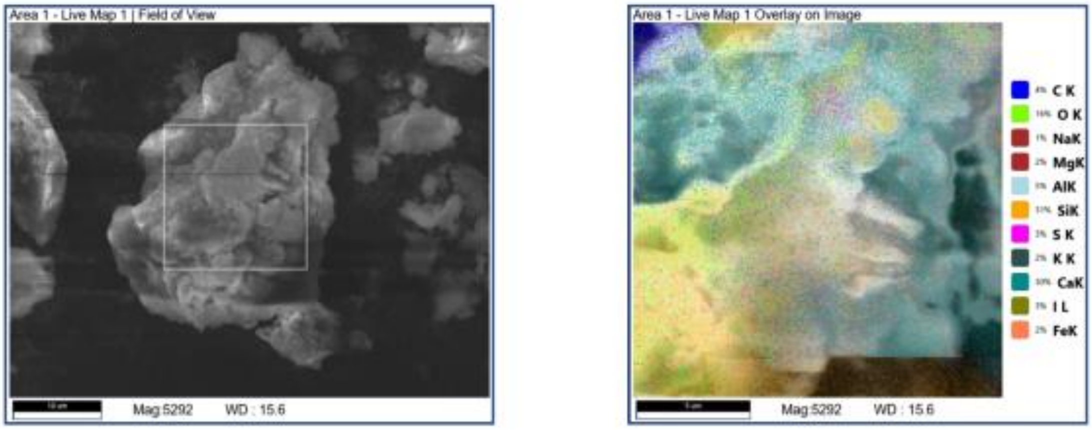


*Figure 15: SEM with back scatter diffraction and element mapping for the control*

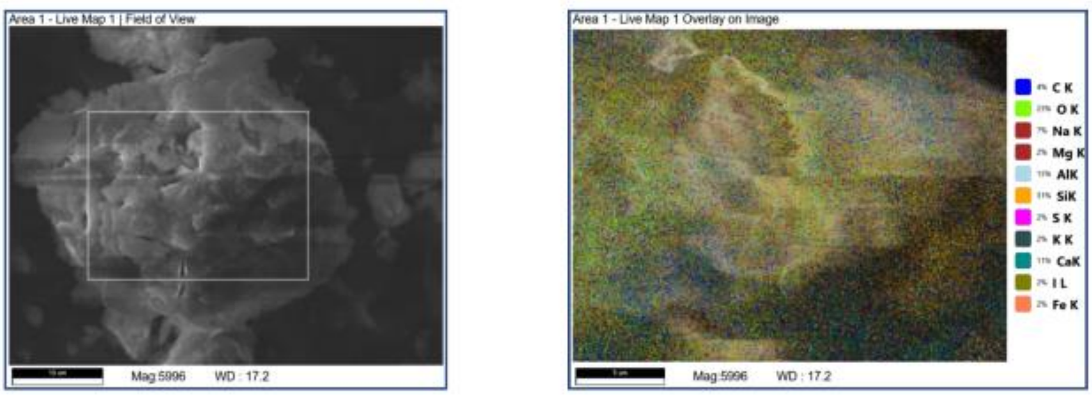


*Figure 16: SEM with back scatter diffraction and element mapping for LBPE sample*

The results indicate that the usual elements in concrete were present in both the control and the LBPE samples. These have been mapped to show their occurrences in detail. Among the major elements, calcium and carbon are more abundant in the control than in the LBPE samples. All other major elements, namely oxygen, Silicon, Aluminium, and Sodium, are more abundant in the LBPE samples than in the control.

## CONCLUSION

The engineering performance of fresh and hardened concrete was enhanced when mixed with locust bean pod extracts. The maximum strength value obtained from the experimental results was

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21.19N/mm$^2$ for 75% replacement with LBPE using four days of LBPE soaking duration. This is a 54.67% increment over the control strength value. The slump value for the same four days of LBPE soaking duration and 75% replacement with LBPE was 95mm, a 21.79% increment over the control slump. This shows that the liquid extracted from the locust bean pod can increase fresh concrete's workability and hardened concrete's strength. The percentage replacements of water with LBPE increased hardened concrete's workability and compressive strength.

Chemical analysis of the LBPE shows the presence of tannins as the primary functional group. Tannins are known to behave as superplasticisers. Locust Bean Pod Extract (LBPE) can be applied successfully in manufacturing concrete works for structures with some percentage water replacement with LBPE. Longer soaking durations beyond one week are not recommended because these gave unfavourable results. The optimum soaking duration to obtain the LBPE and percentage replacement of water with LBPE are four (4) days and 75% of LBPE, respectively.

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