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IMPACT OF LUFFA CYLINDRICAL FIBER ASH ADDITION ON CEMENT PASTE AND CONCRETE CHARACTERISTICS

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ABSTRACT

This study investigates the impact of luffa cylindrical fiber ash (LCFA) on behaviour of cement paste and concrete. LCFA was blended with cement from 0 to 10% by its weight, and laboratory tests were carried out to examine the chemical composition of the ash, as well as its physical properties such as standard consistency and setting time. Standard concrete cubes were cast and cured for 7, 14, and 28 days to determine density and compressive strength, following the requirements of BS EN 12390-3**.** The results of the oxide composition of LCFA revealed that it cannot act as a cement replacement material due to modest SiO_2 content and disproportionately high K_2O level that supports its classification as a low-reactivity and non-pozzolanic biomass ash. Although, the workability results indicated insignificant reduction in slump at high LCFA level, the hardened properties of cement paste and concrete at 28 days curing period, revealed that both density and compressive strength significantly reduced with high LCFA levels; for example, mixes showed reduced compressive strengths from 29.19 to 18.39 MPa. These findings suggest that LCFA lowers the overall performance of concrete when used as additive in cement-based composite. It is therefore more appropriate for non-structural or low-load bearing applications where reduced strength is not a major concern.

Keywords: LCFA, Cement paste, Concrete, Workability, Density, Compressive strength

INTRODUCTION

Concrete remains one of the most widely and predominantly used in civil engineering infrastructural construction materials due to its durability, versatility, and strong structural performance. It occupies virtually 70 % of the volume of concrete structures and demonstrates significant impact (Adamu et al., 2020; Abd-Al Ftah *et al.*, 2022; Tassew & Lubell, 2014).

The rising construction costs, alongside the imperative to mitigate environmental pollution and promote sustainable practices, have spurred research into alternative materials and waste products; such as agricultural or industrial by-products, to partially or wholly substitute expensive traditional ones, thus averting resource depletion, lowering expenses, boosting infrastructure growth, creating jobs, and fostering eco-friendly engineering construction materials (Ugwu & Egwuagu, 2022). Compounding these challenges are the escalating concerns over cement production's high costs, resource demands, and substantial carbon footprint, approximately one ton of CO_2 per ton of clinker, which have intensified the pursuit of greener alternatives (Lin *et al.*, 2006). Notably, agricultural by-products like natural fibers and plant ashes have emerged as promising options, with studies demonstrating their ability to alter the fresh and hardened characteristics of cement-based composites while yielding environmental advantages (Abdullahi, 2006; Ferreira *et al.*, 2022; El-Sayed & El-Samni, 2006; Sholadoye *et al.*, 2023).

Luffa cylindrical fibre, in particular, is an abundant, biodegradable and mechanically promising, and it has been widely explored as a reinforcing material in both polymer and cementitious systems (Akinyemi & Dai, 2022; Al-Mobarak *et al.*, 2018; Alhijazi *et al.*, 2020). While the fibre itself has received significant research attention, its ash; luffa cylindrical fiber ash (LCFA) remains largely underexplored. Previous studies have not adequately examined its chemical suitability, effect on cement paste or concrete, or its potential as either an additive or partial replacement material.

The novelty of this study lies in evaluating LCFA specifically as an ash additive in cement-based composites, which has not been previously characterized in terms of its chemical behaviour, influence on workability, impact on density and strength development. By examining LCFA not as a fibre but as a processed ash, this study introduces new insights into how agricultural wastes from luffa fibres behaves when incorporated into cement systems.

To address this gap, the study investigates the effects of adding LCFA at 0 to10% by weight of Portland limestone cement on the properties of cement paste and concrete. The study evaluates chemical composition, standard consistency, setting time, workability, density and compressive strength to determine whether LCFA can effectively serve as an additive for sustainable and cost-efficient cement-based materials.

MATERIALS AND METHODS

Materials

The materials used in this study are Portland limestone cement, luffa cylindrical fiber ash, fine aggregate, coarse aggregate, and water.

Portland Limestone Cement (PLC)

The Sokoto Portland limestone cement (PLC) of class 42.5 strength, commercially known as BUA cement in Nigeria, which conforms with the requirements of BS EN 197-1 (2000), was used to prepare cement paste and a normal-strength concrete mix.

Luffa Cylindrical Fibre (LCF)

The luffa cylindrical fiber (LCF) is a warm-season crop grown in an open space in the rainy season. It is found in Asian and African countries. The LCF used was obtained within the Birnin Kebbi metropolis, in Kebbi State, Nigeria.

Fine Aggregate

The natural sharp sand utilized in this study for the preparation of the concrete mix was supplied from the

Ambursa Fadama area along the river Rima in Birnin Kebbi Local Government, Kebbi State, Nigeria. The physical properties of the fine aggregate, such as gradation and specific gravity, were investigated in the Waziri Umaru Federal Polytechnic, Birnin Kebbi, Concrete laboratory.

Coarse Aggregate

The angular-shaped granite obtained from the Yauri quarry in Kebbi State, Nigeria, was used for a normal-weight concrete mix of grade 25. The maximum size of 20 mm coarse aggregate was used in this study, and it was found to be free from debris and other impurities.

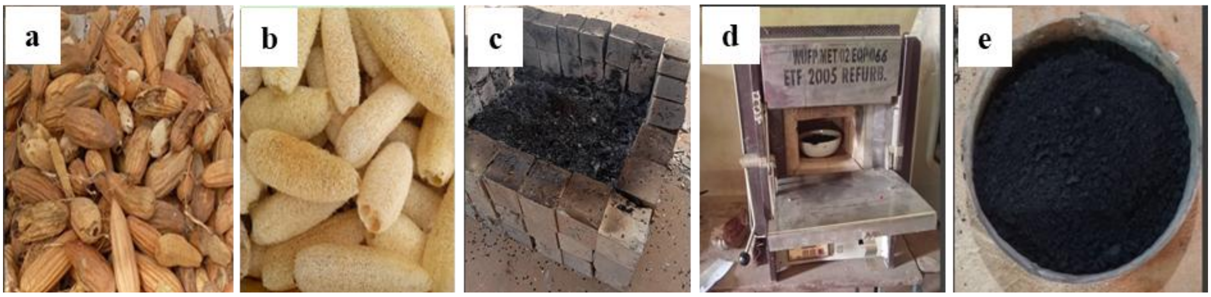
Water

The concrete mixtures were made using water that was pumped from the Waziri Umaru Federal Polytechnic, Birnin Kebbi waterworks. The water quality complied with BS EN 1008 (2000), which stipulates that water used for concrete production must be safe to drink and free of pollutants, color, taste, and odor. Thus, the quality and quantity of water in mixing concrete are very important, as the durability and strength of concrete are reduced due to the presence of chemical impurities in water.

Methods

Preparation of Luffa Cylindrical Fibre Ash (LCFA)

The luffa cylindrical fibers were first air-dried for one week to remove inherent moisture content. The dried fibers underwent controlled open-air burning for full combustion, followed by calcination in a Carbolite ELF series muffle furnace at 600°C for 2 hours with a ramp rate of 5–10°C/min to produce luffa cylindrical fiber ash (LCFA). The ash was allowed to cool slowly in ambient air, then underwent ball milling process to achieve particles finer than PLC, and sieving through a 75µm BS sieve as per ASTM C204. Figure 1 illustrates the LCF-to-LCFA conversion process. The processed LCFA was incorporated into cement paste and concrete mixtures at 0, 2, 4, 6, 8, and 10% by weight of PLC.



Raw LCF **LCF with removed outer skin** **Carbonization of LCF** **Calcination of LCF** **LCFA**

Figure 1: Process of obtaining Luffa Cylindrical Fiber Ash

Table 1 presents the physical properties of LCFA, which include appearance (colour), specific gravity and fineness.

Table 1: Physical Properties of LCFA

Properties	**Colour**	**Specific Gravity**	**Fineness: Passing 75 micron (%)**
Value	Black	1.25	92.5

Oxide Composition by XRF Method

The XRF is a non-destructive analytical technique used to determine the oxide elements composition of materials by detecting fluorescence (or secondary) X-rays produced when the sample is excited by a primary X-ray source from the spectrometer's x-ray tube. The composition of oxide elements in PLC and LCFA was measured using an energy dispersive X-ray fluorescence (EDXRF) spectrometer (Thermo Fisher Model ARL 9900), as specified by ASTM D4326 (2021), to assess suitability for cement-mortar and concrete production. The chemical composition tests were conducted at the Chemical Engineering Department of Ahmadu Bello University, Zaria. To determine the oxide elements, the PLC and LCFA pellets were placed in the XRF spectrometer, which measured the intensities of characteristic X-rays; these intensities were converted to elemental concentrations to analyze major and minor elements. The oxide compounds determined include SiO_2, Al_2O_3, Fe_2O_3 (major oxides), and CaO, SO_3, K_2O, Cl, ZnO, TiO_2, P_2O_5 (minor oxides).

Normal Consistency and Setting Times Tests

The standard consistency test was conducted to ascertain the required water content to produce a cement paste of standard consistency in accordance with BIS: 4031-1988 PART 4. The initial and final setting times were determined in line with BIS: 4031 – 1988 part 5 (Aryal, 2019; Vardhan et al., 2015).

Mechanical Properties of Concrete Constituents

The mechanical properties of concrete constituents were determined in order to ascertain the suitability of the materials used in the research, the specific gravity of Portland limestone cement, coarse aggregate IS 2386 (Part 3)1963, and fine aggregate was determined. Similarly, the silt content of fine aggregate and the soundness of Portland limestone cement were assessed accordingly. Likewise, the ACV and AIV were determined as per IS 2386 (Part 4)1963 and IS 383-1970.

Batching, Mixing, and Casting of Concrete Cubes

In this study, cement-mortar mixes were prepared using a water-cement ratio of 0.5 with an addition of different percentages of LCFA: 0%, 2%, 4%, 6%, 8%, and 10% by weight of Portland limestone cement. Similarly, a concrete of nominal mix ratio 1:2:4 was adopted. The mixtures incorporated with LCFA were batched by weight. The absolute volume method was adopted for the measurement of the constituent materials of concrete. The method is based on the assumption that the volume of the compacted concrete is equal to the sum of the volumes of all the ingredients (Dahiru *et al.*, 2018). The workability test was carried out using the slump method to determine the ease with which the concrete mix could be workable. The test was carried out in accordance with BS 1881 part 102 (1983). Table 2 presents the detailed weight of the various ingredients of PLC-LCFA concrete used in this study.

Table 2: Mix Proportions of LCFA Concrete

Mix ID	LCFA (%)	Cement (kg/m^3)	LCFA (kg/m^3)	W/C	Water (kg/m^3)	FA (kg/m^3)	CA (kg/m^3)
0% LCFA	0	362	0	0.50	181	787	1461
2% LCFA	2	362	7.24	0.50	181	787	1461
4% LCFA	4	362	14.48	0.50	181	787	1461
6% LCFA	6	362	21.72	0.50	181	787	1461
8% LCFA	8	362	28.96	0.50	181	787	1461
10%LCFA	10	362	36.2	0.50	181	787	1461

Compressive Strength Test

One of the most crucial characteristics of concrete is its compressive strength. The tests for compressive strength and density were done at the Civil Engineering laboratory at Waziri Umaru Federal Polytechnic in Birnin Kebbi. Fifty-four (54) concrete cubes (measured 150 mm x 150 mm x 150 mm) were cast and demoulded after 24 hours and hence subjected to full immersion curing in water bath for respective periods of 7, 14, and 28 days. Similarly, the density of all the cubes was determined and tested for compressive strength using a Universal Testing Machine (UTM), as shown in Fig. 2. The tests were conducted on samples of the control mix and samples that had LCFA addition of 2%, 4%, 6%, 8%, and 10% by weight of PLC. Equation 1.0 was used to compute the compressive strength of concrete.

$$Compressive\ Strength = \frac{F}{A} \quad (1.0)$$

Where F = Load at failure (kN) and A = cross-sectional area of the specimen on which compressive force acts (mm^2).

Figure 2: Compressive Strength Testing Machine

Table 3 presents the descriptive statistics of PLC-LCFA concrete, indicating the number of samples allocated to 7, 14 and 28 days curing periods, as well as the mean and standard deviations corresponding to various LCFA levels.

Table 3. Descriptive Statistics for Compressive Strength of PLC-LCFA Concrete

LCFA (%)	Curing Age (Days)	No. of Sample per age	Mean (MPa)	Std. Dev (MPa)	Min (MPa)	Median (MPa)	Max (MPa)
0	7	3	22.22	3.97	19.65	20.22	26.80
0	14	3	29.19	3.11	25.61	30.78	31.19
0	28	3	28.81	0.30	28.47	28.92	29.04
2	7	3	21.98	1.58	20.23	22.41	23.29
2	14	3	23.89	9.11	13.44	28.06	30.16
2	28	3	28.74	1.17	27.86	28.30	30.07
4	7	3	21.10	0.89	20.11	21.34	21.84
4	14	3	24.56	1.05	23.80	24.12	25.75
4	28	3	24.71	2.18	22.24	25.52	26.36
6	7	3	17.38	2.81	14.29	18.07	19.77
6	14	3	20.05	2.23	17.50	21.03	21.63
6	28	3	20.02	2.26	17.86	19.83	22.36
8	7	3	20.34	0.63	19.62	20.65	20.75
8	14	3	18.33	3.46	14.35	20.08	20.56
8	28	3	20.02	2.26	17.86	19.83	22.36
10	7	3	15.42	1.44	13.79	15.94	16.52

LCFA (%)	Curing Age (Days)	No. of Sample per age	Mean (MPa)	Std. Dev (MPa)	Min (MPa)	Median (MPa)	Max (MPa)
10	14	3	16.71	1.38	15.22	16.94	17.96
10	28	3	18.39	1.03	17.21	18.94	19.03

RESULTS AND DISCUSSION

Preliminary Test of the Concrete Constituents

The properties of the concrete constituents are illustrated in Table 4. The Portland limestone cement's specific gravity value was found to be 2.96, conforming to the requirements of BS (Aliyu *et al.*, 2023; Bakar *et al.*, 2016). The soundness of Portland cement was determined as 3.5 mm, which amply demonstrates that it falls within the EN 197-1 standard's specified range of no more than 10 mm (Haruna *et al.*, 2021; Sholadoye *et al.*, 2023). The specific gravity of coarse aggregate was found to be 2.67, falling within the permissible range of 2.5 to 3.0 needed in a concrete mix, agreeing with the ASTM C127 standards (Ajagbe *et al.*, 2015; Maina *et al.*, 2022). Whereas that of fine aggregate was obtained as 2.58. The fine aggregate's percentage of silt content was found to be 6.98%. For engineering construction, a silt-clay content of fine aggregate ranging from 3 to 8% is comparatively suitable (Abdullahi & Abdullahi, 2006). The average aggregate crushing value (ACV) was obtained as 29%. As contained in BS 812-110, the aggregate is excellent (0 to 30%). Consequently, the coarse aggregate exhibits a lower crushing value, leading to a longer service life and enhanced cost-effectiveness (Sholadoye *et al.*, 2023). Similarly, the aggregate impact value (AIV) was computed as 21% in line with the BS 812-112 (Das *et al.*, 2021). The aggregate is exceptionally strong; this shows that the aggregate can withstand sudden impact.

Table 4: Mechanical Properties of the Concrete Constituents

Description of Test	Results
Specific Gravity of Portland Cement (BUA)	2.96
Specific Gravity of Coarse Aggregate	2.67
Specific Gravity of Fine Aggregate	2.58
Percentage of Silt of fine aggregate (%)	6.98
Aggregate Crushing Value (%)	29.0
Aggregate Impact Value (%)	2.0
Soundness (mm)	3.5

Figures 3 and 4 presents the gradation curves for natural coarse and fine aggregates respectively. As deduced from Fig. 3, the fine aggregate was classified as uniformly graded based on the uniformity and curvature coefficients of 2.00 and 1.00 respectively. Likewise, the coarse aggregate had respective coefficients of 1.53 and 1.08 as deduced from fig. 4. As such, based on grading requirements, the mixes could be hashed and may lead to water demand in PLC-LCFA concretes.

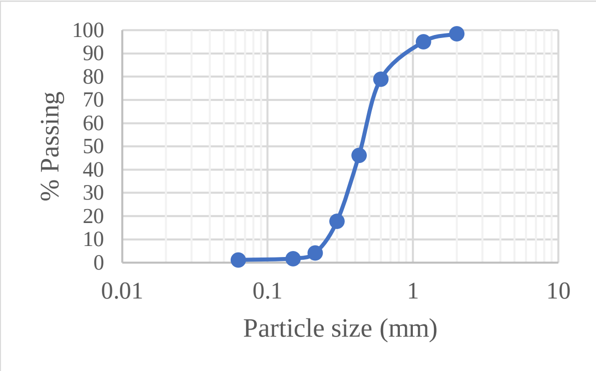


Figure 3: Fine Aggregate Grading Curve

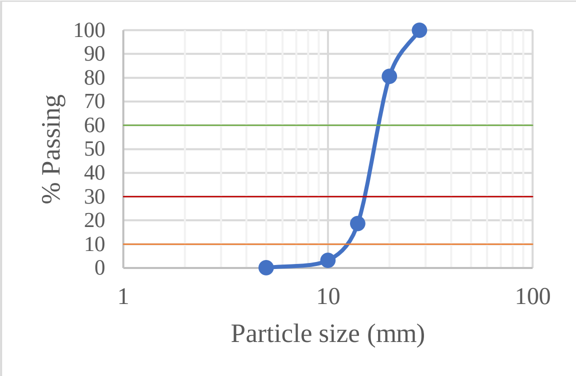


Figure 4: Coarse Aggregate Grading Curve

Oxide Composition of Cement and LCFA

The oxide compositions of PLC and LCFA are presented in Table 5. The results revealed that the LCFA contains a large percentage of K_2O (52.218%) compared to that of cement (0.51%). The composition of silica (SiO_2), alumina (Al_2O_3), and iron oxide (Fe_2O_3) in LCFA is less than 70%. Therefore, in accordance with ASTM C681-2005, the LCFA cannot be used as a pozzolanic material. This is consistent with earlier research that found in (Çolak, 2003; Sholadoye *et al.*, 2023).

Table 5: Oxide Composition of Cement and LCFA

Chemical Composition	SiO_2	Al_2O_3	Fe_2O_3	CaO	SO_2	K_2O	CI	ZnO	TiO2	P_2O_5
PLC (%)	11.27	4.922	2.965	75.01	3.14	0.51	0.42	0.01	0.209	0.000
LCFA (%)	9.243	3.016	1.975	13.628	3.261	52.218	5.874	0.048	0.277	7.354

Normal Consistency Test of Cement Paste

The setting time of cement paste containing different additives of LCFA is illustrated in Table 6. The results show that as the percentage addition of LCFA increases, the water content also increases from 37% for the control sample to 46% for the 10% addition of LCFA. This shows that the incorporation of the LCFA in cement paste absorbs more water than the control sample. The increase in water absorption with an increase in LCFA addition is consistent with the work of El-Sayed & El-Samni, (2006).

Table 6: Normal Consistency Test of Cement Paste

Percentage of Ash Addition (%)	Normal Consistency (%)	Remark
0	37	Satisfactory
2	38	Satisfactory
4	40	Satisfactory
6	42	Satisfactory
8	45	Satisfactory
10	46	Satisfactory

Setting Time of Cement

Fig. 5 shows the setting time of cement paste containing different percentages of additives of LCFA. The results reveal that as the addition of the percentage of LCFA increases, the initial and final setting times decrease; thus, it accelerates the setting time of cement paste.

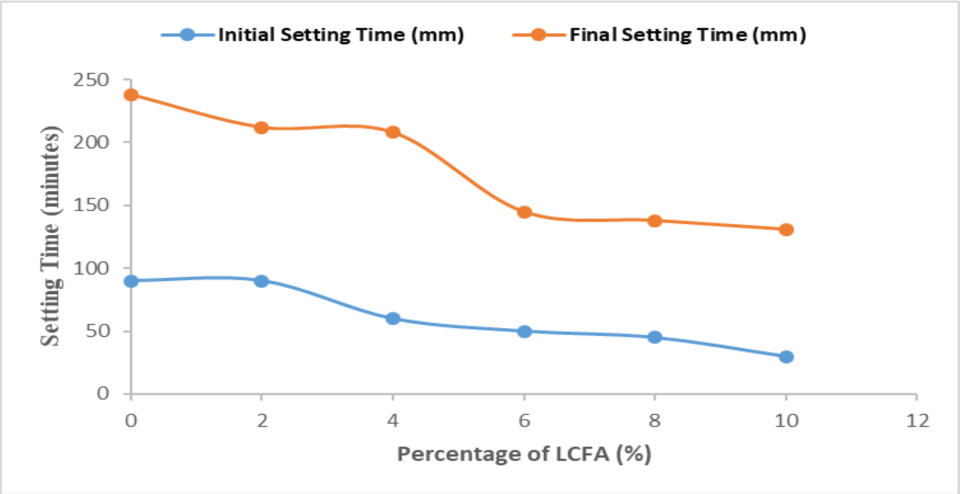


Figure 5: Setting Time of Blend of PLC-LCFA Paste

Concrete Workability (Slump)

Table 7 presents the results of workability for PLC-LCFA concrete. The control mix demonstrates a medium slump value of 55 mm, which falls within the range of 50 to 100 mm, while the mixes with LCFA addition exhibit low slump values ranging from 0 to 50 mm according to ASTM C 143. Additionally, medium workability concrete can be used for slabs, beams, and columns, whereas low workability concrete is suitable for roads, pavements, foundations, and lightweight structures (Sada *et al.*, 2013).

The slump results show a clear reduction in workability as LCFA content increases, dropping from about 55mm for control mix to 9mm at 10% LCFA, indicating that the ash significantly stiffens the fresh concrete. This trend aligns with the setting-time behaviour of the PLC-LCFA paste, where both the initial and final setting times decrease with higher LCFA proportions, suggesting an accelerated hydration process and faster loss of plasticity. The rapid setting is likely linked to the unusually high alkali content of LCFA, particularly its elevated K_2O level; which can increase ionic concentration in the paste, speed up early reactions, and reduce the time available for workable flow (Tangchirapat *et al.*, 2013; Zhang & Chen, 2022). In laboratory conditions, these combined effects imply that LCFA reduces both workability and setting time, making fresh concrete more difficult to handle without chemical admixtures or additional water, which could compromise long-term performance. In real-world applications, such behavior limits the use of LCFA concrete in situations requiring high workability, complex formwork, or hot-weather concreting. However, the faster setting may be advantageous for small-scale repairs or rapid-construction tasks, provided mix adjustments are made to control shrinkage and early-age cracking (Amin *et al.*, 2023). Despite these challenges, LCFA remains valuable from sustainability viewpoint, although its practical use demands careful mix optimization and close control of fresh-state properties (Okafor et al., 2024).

Table 7: Concrete Slump at Different LCFA Addition Levels

Percentage of LCFA Addition (%)	Slump Value (mm)	Specification (ASTM C 143) (mm)	Remark
0	55	50 - 100	Medium slump
2	37	0 - 50	Low slump
4	25	0 - 50	Low slump
6	18	0 - 50	Low slump
8	12	0 - 50	Very low slump
10	9	0 - 50	Very low slump

Hydration and Workability of PLC-LCFA

The compressive-strength results show that concrete incorporating LCFA consistently performs lower than the control mix at 7, 14 and 28 days, with strength gradually decreasing as the LCFA content increases. This outcome aligns with the ash's very low pozzolanic reactivity, which limits its ability to contribute to the secondary C–S–H formation that normally enhances long-term strength when effective SCMs are used (Amin et al., 2023). The chemical data further explain this behaviour: LCFA contains an exceptionally high amount of K_2O (52.218%), far above the level found in Portland limestone cement. Such a high alkali load can disrupt early hydration, raise the likelihood of alkali–silica reactions, and generally weaken the internal structure of the paste (Zhang & Chen, 2022). In controlled laboratory tests, this high K_2O concentration and low reactivity make LCFA act more like a non-reactive filler than a binder. In practical construction settings, these findings suggest that LCFA is more appropriate for non-structural or low-load applications, especially where sustainability and waste reduction are priorities. Still, LCFA's value lies in resource conservation and waste utilization, although its high alkali content means that careful mix design or blending with more reactive SCMs is necessary to reduce performance risks (Okafor *et al.,* 2024).

Compressive Strength Test

Before determination of compressive strength, the density of the mixed samples of 0%, 2%, 4%, 6%, 8%, and 10% containing the addition of percentages of LCFA was determined as 2531.37 kg/m³, 2444.44 kg/m³, 2439.51 kg/m³, 2385.17 kg/m³, 2375.19 kg/m³, and 2214.82 kg/m³. As the proportion of LCFA increased, the density was seen to decrease. Even though the density decreased due to the higher percentage of LCFA added, the concrete nevertheless satisfies BS 206-1's requirements for lightweight concrete, which is inconsistent with research by Sada *et al.,* (2013). The mean compressive strength of concrete of various mixes of 0%, 2%, 4%, 6%, 8%, and 10% containing the addition of percentages of LCFA by weight of Portland limestone cement are plotted in Fig. 6. The strength values recorded at 7 days for the control (0%) sample were 22.22 N/mm², 2% had 21.98 N/mm², while 10% had the least compressive strength of 15.42 N/mm². Similarly, the strength value of the 14-day curing age of the control sample (0%) was observed as 27.89 N/mm², 2% had 24.56 N/mm², while the lowest strength of 16.71 N/mm² was recorded at 10% LCFA addition. Furthermore, the compressive strength determined at 28 days for 0%, 2%, and 10% was 29.19 N/mm², 28.74 N/mm², and 18.39 N/mm², respectively. This implies that 2.0% exhibited a percentage decrease in compressive strength of 1.54% when compared with the control at a 28-day curing period, while at 10% addition of LCFA, there was a decrease in compressive strength of 37%. The results reveal that as the curing ages and the additive percentages of LCFA increase, the compressive strength decreases. It was stated that the addition of natural fiber ash containing high alkaline (K_2O) to concrete mix leads to expansion and cracking, thereby reducing its compressive strength (Ardalan, 2024). As can be inferred from the plot, only the 2% addition had compressive strength close to the control at all the curing ages. This is demonstrated by the oxide composition test findings in Table 2, which show that the LCFA is a non-pozzolanic substance and does not react with calcium hydroxide to produce calcium silicate hydrate gel (CSH) or other cementitious compounds. Consequently, it restricts the concrete's ability to develop strength; this is consistent with earlier research that found it unsuitable for engineering construction (Çolak, 2003).

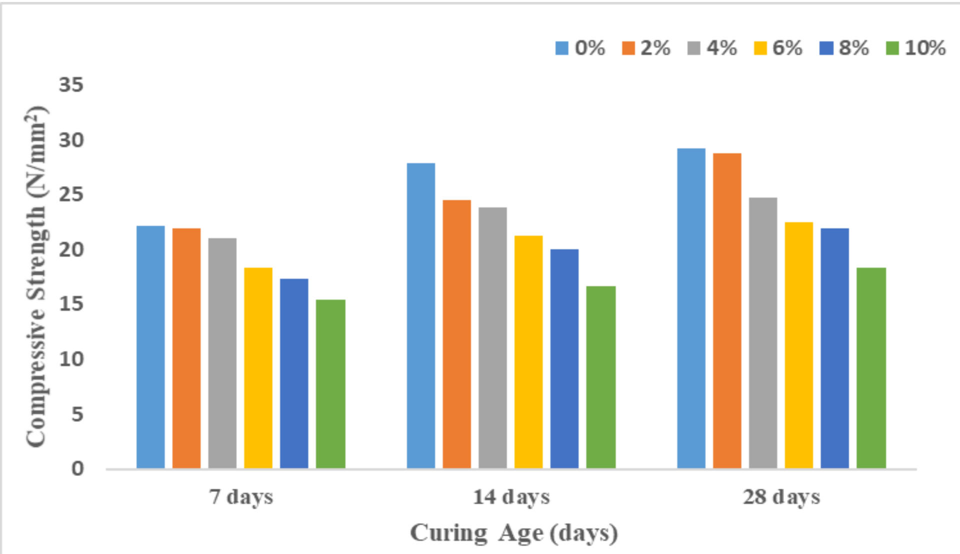


Figure 6: Compressive Strength of Concrete with Varied Percentage of LCFA

CONCLUSIONS

This study aimed at analyzing the impact of luffa cylindrical fiber ash (LCFA) addition on the cement paste and concrete characteristics by incorporating LCFA at different percentages of 0%, 2%, 4%, 6%, 8%, and 10% by weight of Portland limestone cement (PLC) to provide an alternative use of LCFA to the Portland limestone cement in the production of cement paste and concrete mixtures. The following conclusions were drawn:

1. The chemical analysis shows that LCFA does not meet the required levels of SiO_2, Al_2O_3 and Fe_2O_3 to act as a pozzolanic material, so it works mainly as a non-reactive filler.
2. The basic properties of the materials used in making the concrete were found to be acceptable and suitable for construction purposes.
3. As more LCFA was added, both the initial and final setting times became shorter, meaning the cement paste

set faster—mainly because of the very high K_2O content in the ash.

4. Slump values became lower with higher LCFA content, showing that the concrete became less workable and stiffer when LCFA was increased.
5. Compressive strength decreased as LCFA content increased, with only the 2% LCFA mix giving strength values close to the control mix. Higher LCFA levels weakened the concrete because the ash has very low reactivity.

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