



Research Article

Comparative Study on Mechanical Properties of Concrete Blended with *Costus englerianus* Bagasse Ash and Bagasse Fibre as Partial Replacement for Lime and Cement

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Nowadays, researchers have been on the lookout for eco-sustainable additives such as agro/industrial waste in concrete in order to offset the carbon footprint created by cement manufacturing. However, it has been said that the use of agro/industrial-waste-based cementitious materials in concrete improves its quality. However, this study compared the performance of hydrated lime and cement concrete replaced with 5% and 10% *Costus englerianus* bagasse ash and bagasse fibre for determining the mechanical properties (compressive and flexural strength). Moreover, compressive strength was evaluated on cubical specimens and flexural strength was evaluated on beam samples at 7, 14, and 28 days, respectively. Results showed that the compressive strength and flexural strength of the concretes increased with an increase in the curing age. Also, the compressive and flexural strengths of cement concrete were recorded by 65.38 MPa and 10.86 MPa at 0% bagasse ash or fibre, which performed better than concrete replaced with 5% and 10% bagasse ash and fibre at 28 days, respectively. Besides, the compressive strength of concrete was noted by 53.85 MPa and 48.92 MPa at 10% bagasse ash and 10% bagasse fibre, respectively, while the flexural strength was calculated by 6.86 MPa and 5.54 MPa at 10% bagasse ash and 10% bagasse fibre, respectively, which were higher than that of concrete produced with hydrated lime alone at 28 days. Thus, bagasse ash performed better than bagasse fibre ash as a partial replacement of cement or hydrated lime in concrete production. Therefore, *Costus englerianus* bagasse ash or bagasse fibre improved the performance of hydrated lime concrete at 5–10% replacement, but higher concrete strength would be obtained in cement replacement than hydrated lime.

1. Introduction

Concrete is only second to water as the most widely used materials in the world, which was estimated at 30 billion tons per yearly consumption [1]. The demand for high-strength concrete in building infrastructures has been on the increase, but increasing the strength of concrete could equally increase its brittleness, which ultimately may lead to crack and

failure of concrete structures [2–6]. However, the development of new cementitious materials could improve the safety, durability, and sustainability of concrete [7–10]. The addition of pozzolan materials in cement enhanced the mechanical properties of concrete, such as compressive, tensile, and flexural strength [11, 12].

Lime, as binding material, yields concrete with low strength, which may not be useful in certain areas of

construction [13–17]. In a study by Salman and Muttar [18], the optimum compressive strength of Portland cement concrete obtained at 28 days of curing was 26.96 N/mm^2 , but just 6.12 N/mm^2 was recorded at 28 days of curing for lime concrete and only increased by 50% (13.15 N/mm^2) when the curing period was increased to 90 days. However, Awodiji et al. [14] recommended the addition of pozzolanic materials in lime concrete to increase the lime concrete strength designed for construction purposes. Brzyski [19] reported an increase in the strength of concrete by adding 10% meta-kaolinite, micro silica, and zeolite, independently, in lime concrete, which doubled the strength by 20%.

The use of agricultural waste ash as a cement substitute is gaining popularity among academics owing to its eco-friendliness, sustainability, and economic benefits [20–22]. Portland cement (PC) concrete is utilized in a wide variety of structural applications, and modern and complex designs need a substantial amount of PC [23]. But PC production is one of the most energy-intensive processes in concrete [24–27], and it also produces carbon dioxide which has been a cause of discomfort for the atmosphere. PC manufacturing accounts for between 5% and 7% of industrial carbon dioxide emissions [28–31]. Additionally, affordable housing has grown more difficult to get for many low-income workers in a number of developing nations owing to the high cost of construction ingredients, notably cement. Without impacting the performance of concrete buildings, the amount of Portland cement must be lowered to help limit emissions of carbon dioxide and offer sustainable building materials [32, 33]. However, a partial replacement of PC using combined cement replacing materials (CRMs) is favorable in terms of economics, mechanical properties, and microstructure. There are various commonly produced CRMs that could be used in concrete. Millet husk ash (MHA), sugarcane bagasse ash (SCBA), coconut shell ash (CSA), groundnut shell ash (GSA), silica fume (SF), maize cob ash (MCA), wheat straw ash (WSA), and rice husk ash (RHA) are among the most commonly used products [34, 35]. Reusing these CRMs offers a practical solution to contamination, waste management, and excessive cement costs. Therefore, *Costus englerianus* bagasse ash and bagasse fibre are used as cementitious material in this experimental work. Moreover, *Costus englerianus* bagasse is a family of sugarcane bagasse that mostly grows in the bush with stronger fibres than sugarcane bagasse. *Costus englerianus* bagasse has not attracted wide attention as a partial replacement of cement in concrete production. On the other hand, sugarcane bagasse ash as pozzolan materials has shown effectiveness in the enhancement of mechanical properties and durability of concrete [36–38]. Malyadri and Supriya [39] reported a 5% increase in concrete strength using sugarcane bagasse ash as a partial substitute for cement. A similar observation was also reported by Mangi et al. [40]. Between 5% and 20% sugarcane bagasse ash replacement, an acceptable strength of concrete can be obtained [41, 42]. Other studies have shown that sugarcane bagasse is a good replacement material for concrete production [43, 44]. Also, 5 to 15% sugarcane bagasse ash increased the compressive strength and workability of concrete [45–47],

while other authors have recorded compressive strength produced from sugarcane bagasse ash that was higher than cement concrete alone at 5% replacement or more [48–51]. An excessive increase in the percentage replacement of bagasse ash could result in reduced strength of concrete [52–55].

Furthermore, some studies were performed on the concrete blended with cement and lime as cementitious material. But no experiments were performed on concrete incorporating the combining influences of PC and lime replaced with *Costus englerianus* bagasse ash and fibre for determining the mechanical properties of concrete. Therefore, this research is performed to determine the mechanical properties of concrete blended with PC and lime replaced with *Costus englerianus* bagasse ash and fibre in the mixture, respectively.

2. Materials and Methods

2.1. Materials. The materials used in the study include hydrated lime and limestone cement (Dangote cement) as the binder, *Costus englerianus* bagasse ash and bagasse fibre as pozzolan materials, granite chipping as coarse aggregates, river sand as fine aggregates, clean tap water, and superplasticizer. However, the stems of *Costus englerianus* bagasse were collected from bushes in the Odiokwu community, Ahoada West Local Government Area of Rivers State, Nigeria, and sundried for 72 hours at atmospheric temperature to remove the moisture content. Parts of the dried samples were burnt to ashes in open air and sieved to remove the carbonaceous material. The free carbonaceous burnt ashes (bagasse ash) were ground to fine particle sizes, while the remaining parts of the dried samples (bagasse fibre) were also ground to fine particle sizes. The ground fine particles of the bagasse ash and bagasse fibre were sieved to $90 \mu\text{m}$ uniform sizes and stored in airtight containers. The limestone cement (Grade 42.5R) and hydrated lime were purchased from a building material shop in Port Harcourt, Rivers State. The chemical composition and properties of cement, bagasse ash, and bagasse fibre are shown in Table 1. River sand was collected from the Sombrero River in Ahoada East Local Government Area of Rivers State and poorly graded to $<5 \text{ mm}$ in size which was used for this research. Besides, granite chippings were used as coarse aggregates (CA) having 20 mm in size which were bought from a retailer in Rivers State. In addition, polycarboxylate polymer superplasticizer (SP) (Auracast 200) was obtained from a building material store in Port Harcourt, while tap water was collected from the laboratory.

2.2. Mix Proportions. The bagasse ash and bagasse fibre were prepared at replacement percentages of 5% and 10% and mixed with cement, fine and coarse aggregates. Concrete cubes including 0% bagasse content (with only cement or hydrated lime) from the mix proportions were cast with the following dimensions: $150 \text{ mm} \times 150 \text{ mm} \times 150 \text{ mm}$ to test for compression strength, while the test for flexural strength was conducted on casted beams (including sample with only

TABLE 1: Chemical and physical properties of lime and *Costus englerianus* bagasse.

Composition (%)	Limestone cement	Bagasse ash	Bagasse fibre
SiO ₂	20.36	64.85	56.78
Al ₂ O ₃	5.15	5.36	6.73
Fe ₂ O ₃	2.98	4.72	7.52
CaO	64.07	1.78	5.31
MgO	1.33	1.23	4.65
K ₂ O	0.52	6.41	8.92
Na ₂ O	0.2	1.02	4.17
MnO	—	0.05	0.94
TiO ₂	0.22	—	—
H ₂ O	0.52	0.2	3.76
SO ₃	2.03	0.18	1.03
LOI	2.76	10.48	7.4
SiO ₂ + Al ₂ O ₃ + Fe ₂ O ₃	—	74.93	71.03
Density (g/cm ³)	3.11	2.16	2.25
Specific surface area (cm ² /mg)	3586	4727	2850.8

cement or hydrated lime) with the following dimensions: 500 mm × 100 mm × 100 mm. The samples were mixed at a water binder ratio of 0.32 and cement content of 550 kg/m³. The cubes and beams were cured for 7, 14, and 28 days by immersion in a water tank at room temperature. The mix proportions of concrete are shown in Table 2.

2.3. Testing Methods. The mechanical properties are in terms of compressive and flexural strength. However, the compressive strength test was carried out according to BS EN 12350-3:2009 [56], in which the specimens were crushed at a 15 N/mm² constant rate increase in stress using the universal crushing machine. The cubes were centrally placed on the crushing machine with a smooth surface and allowed to fail under direct axial compressive load. Similarly, the flexural strength test was carried out according to BS EN 12390-5:2009 [57]. The load under which the specimen failed was recorded from which the flexural strength was calculated. All these tests were cured at 7, 14, and 28 days respectively.

3. Results and Discussions

The comparative results obtained for compressive and flexural strength of cement and hydrated lime concrete replaced at 5% to 10% *Costus englerianus* bagasse ash and bagasse fibre are presented and discussed in this section.

3.1. Compressive Strength. The comparative analysis of compressive strength of concrete produced from the bagasse ash and bagasse fibre as partial replacement of cement and hydrated lime was investigated at curing age of 7, 14 and, 28 days with a percentage replacement of 5%, 10%, 15%, and 20% bagasse ash and bagasse fibre. It has been observed that the experimental work is performed by using cement and hydrated lime as binders, and these binders are replaced with various proportions of bagasse ash and bagasse fiber for determining the compressive strength of concrete respectively. The profiles of the compressive strength of concrete produced from the two types of binders are shown in Figures 1–4. Figure 1 shows the profiles for compressive strength comparison of cement and lime concretes

produced at 5% bagasse ash and bagasse fibre between the curing age of 7 and 28 days. The profiles showed that the compressive strength of bagasse ash at 5% replacement was higher than that of bagasse fibre at 5% replacement for both cement and lime concretes. Also, the compressive strength of 0% bagasse (cement only) concrete was greater than the strength of concretes produced with 5% bagasse ash and bagasse fibre, while the strength of concrete with 5% bagasse ash was higher than that of 0% bagasse lime (lime alone) concrete. Furthermore, compressive strength at 5% bagasse ash and bagasse fibre increased with an increase in curing age. Thus, compressive strength between 7 and 28 days increased from 56.74 to 65.38 N/mm² for concrete with cement only, while with only lime or zero per cent bagasse, the compressive strength ranged from 38.01 to 46.47 N/mm². Similarly, the compressive strength between 7 and 28 days increased from 53.86 to 63.95 N/mm² at 5% cement replacement with bagasse ash compared to 39.12–44.87 N/mm² increase in lime concrete with 5% bagasse ash content. Also with 5% bagasse fibre, compressive strength ranged from 51.08 to 59.65 N/mm² and 37.19 to 45.53 N/mm² for cement and lime concretes, respectively.

Similarly, the profiles comparing the compressive strength of cement and lime concrete replaced with 10%, 15%, and 20% bagasse ash and bagasse fibre are shown in Figures 2–4, respectively. The analysis showed that compressive strength increased with an increase in curing age. In addition, the compressive strengths of cement and lime concrete replaced with bagasse ash were higher than those replaced with bagasse fibre. Again, the compressive strengths of cement concrete replaced with bagasse ash and bagasse fibre were higher than those produced with lime concrete at any percentage replacement (see Figures 2–4). This implied that cement is a better binding material for concrete compared to hydrated lime. Previous investigations on the performance of cement and hydrated lime concrete or mortar also showed that the compressive strength of cement concrete performed better than lime concrete [14, 15, 18], which was attributed to the slow rate of the hydration process in lime concrete [15].

The study also showed that the compressive strength of hydrated lime was improved when 10% to 15% bagasse ash and bagasse fibre was added to the mix. Ordinarily, the

TABLE 2: Mix proportions of concrete.

Mix ID	Cement	Lime (%)	Ash (%)	Fibre (%)	Sand (%)	CA (%)	Water/cement ratio	SP (%)
Cement	100	0	0	0	100	100	0.32	1
5% A-Cem	95	0	5	0	100	100	0.32	1
10% A-Cem	90	0	10	0	100	100	0.32	1
15% A-Ceme	85	0	15	0	100	100	0.32	1
20% A-Ceme	80	0	20	0	100	100	0.32	1
5% F-Cem	95	0	0	5	100	100	0.32	1
10% F-Cem	90	0	0	10	100	100	0.32	1
15% F-Cem	85	0	0	15	100	100	0.32	1
20 F-Cem	80	0	0	20	100	100	0.32	1
Lime	0	100	0	0	100	100	0.32	1
5% A-Lime	0	95	5	0	100	100	0.32	1
10% A-Lime	0	90	10	0	100	100	0.32	1
15% A-Lime	0	85	15	0	100	100	0.32	1
20% A-Lime	0	80	20	0	100	100	0.32	1
5% F-Lime	0	95	0	5	100	100	0.32	1
10% F-Lime	0	90	0	10	100	100	0.32	1
15% F-Lime	0	85	0	15	100	100	0.32	1
20 F-Lime	0	80	0	20	100	100	0.32	1

Note: A = ash, F = fibre, CA = coarse aggregates, and SP = superplasticizer.

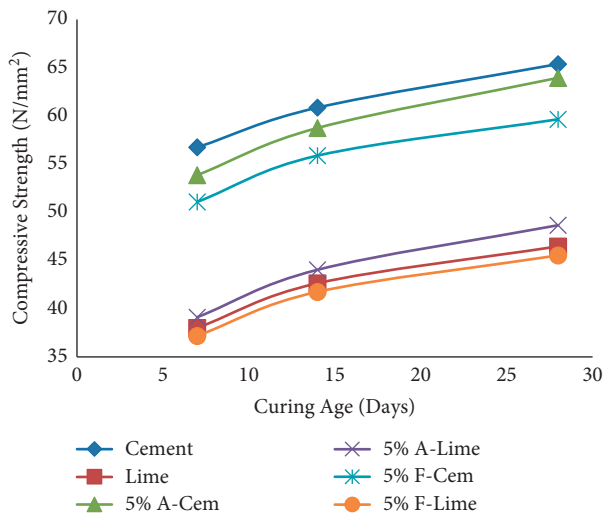


FIGURE 1: Compressive strength of cement and lime with 5% bagasse ash and fibre.

compressive strength of the lime concrete would result in low compressive strength that may not be suitable for structures that require high-strength concrete, but with the addition of other pozzolan materials [18, 58] or inclusion of superplasticizer [59–61], the compressive strength of lime concrete can be improved significantly. Thus, the compressive strengths recorded in this study were very high compared to other studies using sugarcane bagasse ash [2, 49, 51], which is attributed to the addition of a superplasticizer.

3.2. Flexural Strength. The flexural strength of concrete produced from limestone cement and hydrated lime was also investigated at only 5% and 10% bagasse ash and bagasse fibre replacement. The test results are presented for 5% and 10% bagasse ash and fibre as shown in Figures 5 and 6,

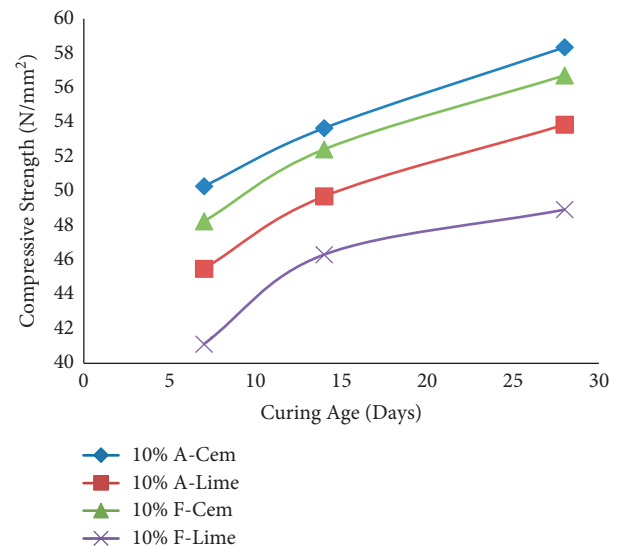


FIGURE 2: Compressive strength of cement and lime with 10% bagasse ash and fibre.

respectively. However, Figure 5 shows the flexural strength of cement and hydrated lime concretes produced with 5% bagasse ash and bagasse fibre replacement for 7, 14, and 28 days of curing age, while Figure 6 shows 10% bagasse ash and bagasse fibre replacement. Similar to compressive strength, the flexural strength of concrete increased with an increase in curing age. Also, the flexural strength of cement concrete with 0% bagasse ash or bagasse fibre (cement only) was more than that of concrete mixed with 5% bagasse ash or bagasse fibre. On the contrary, the flexural strength of lime concrete with 0% bagasse ash or bagasse fibre (lime only) was less than that of concrete mixed with 5% bagasse ash and slightly greater than concrete with 5% bagasse fibre replacement. Thus, between 7 and 28 days of the curing age, the flexural strength obtained for concrete mixed with cement ranged from 9.64–10.86 N/mm² compared to 3.15–5.31 N/mm²

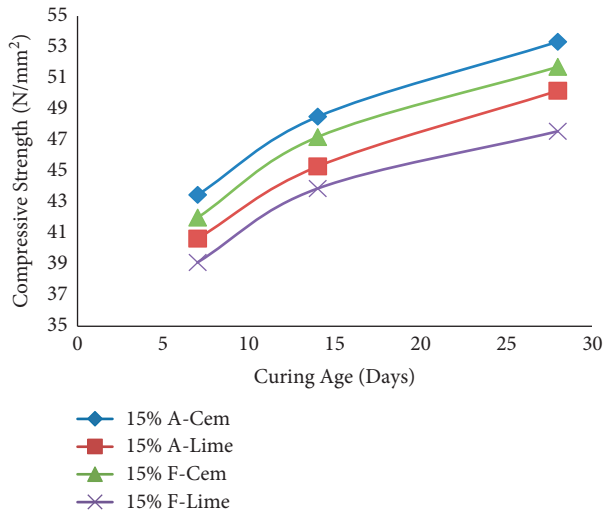


FIGURE 3: Compressive strength of cement and lime with 15% bagasse ash and fibre.

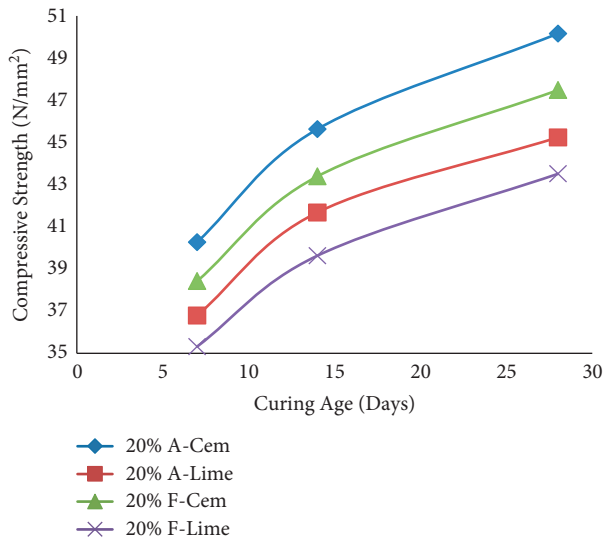


FIGURE 4: Compressive strength of cement and lime with 20% bagasse ash and fibre.

recorded for the mix with lime only. Also at 5% bagasse ash replacement, the flexural strength ranged from 9.29 to 10.55 N/mm² for cement and 3.76 to 5.94 N/mm² for hydrated lime. Similarly, at 5% bagasse fibre replacement, the flexural strength ranged from 7.58 to 8.68 N/mm² for cement and 2.88 to 4.85 N/mm² for hydrated lime.

Similarly, the flexural strength of concrete with cement only was more than that of concrete replaced with 10% bagasse ash and bagasse fibre, but the flexural strength of lime concrete replaced with 10% bagasse ash or bagasse fibre was greater than the flexural strength produced from concrete with lime only (Figure 6). Again, the flexural strength of concrete with bagasse ash performed better than bagasse fibre. The flexural strength obtained for limestone cement replaced by *Costus englerianus* bagasse ash or fibre was within the range reported in previous studies for sugarcane bagasse ash [2, 51, 61–63].

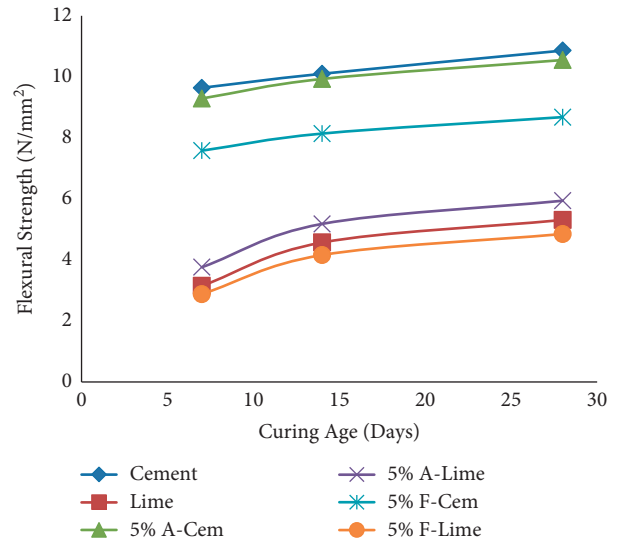


FIGURE 5: Flexural strength of bagasse ash concrete at 5% replacement.

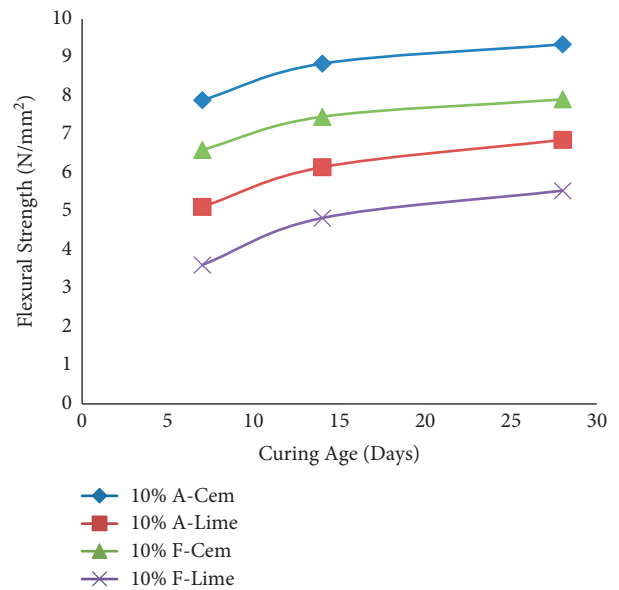


FIGURE 6: Flexural strength of bagasse ash concrete at 10% replacement.

4. Conclusion

The following conclusions were observed from the comparison of the performance of *Costus englerianus* bagasse ash and bagasse fibre as a partial replacement of cement and hydrated lime for the production of concrete suitable for use in the construction industry [63].

- (i) The compressive strengths of concrete were measured by 63.95 MPa, 58.34 MPa, 53.34 MPa, and 50.15 MPa at 5%, 10%, 15%, and 20% of PC replaced with *Costus englerianus* bagasse ash while the compressive strength of concrete was noted by 59.65 MPa, 56.71 MPa, 51.72 MPa, and 47.48 MPa at 5%, 10%, 15%, and 20% of *Costus englerianus*

bagasse fibre as the cementitious material at 28 days, respectively.

- (ii) The compressive strengths of lime concrete were measured by 48.66 MPa, 53.85 MPa, 50.18 MPa, and 45.24 MPa at 5%, 10%, 15%, and 20% of lime replaced with *Costus englerianus* bagasse ash at 28 days, respectively. Besides, the compressive strength of lime concrete was noted by 45.53 MPa, 48.92 MPa, 47.57 MPa, and 43.51 MPa at 5%, 10%, 15%, and 20% of *Costus englerianus* bagasse fibre as the cementitious material at 28 days, respectively.
- (iii) The flexural strengths of concrete were measured by 10.55 MPa and 9.34 MPa at 5% and 10% of PC replaced with *Costus englerianus* bagasse ash while the flexural strength of concrete was noted by 8.68 MPa and 7.91 MPa at 5% and 10% of *Costus englerianus* bagasse fibre as the cementitious material at 28 days, respectively.
- (iv) The flexural strengths of lime concrete were measured by 5.94 MPa and 6.86 MPa at 5% and 10% of lime replaced with *Costus englerianus* bagasse ash at 28 days, respectively. Besides, the flexural strength of lime concrete was noted by 4.85 MPa and 5.54 MPa at 5% and 10% of *Costus englerianus* bagasse fibre as the cementitious material at 28 days, respectively.
- (v) Compressive and flexural strengths of concrete replaced with 5% and 10% bagasse ash and 10% bagasse fibre were higher than the compressive strength obtained from concrete produced with hydrated lime alone. Bagasse ash performed better than bagasse fibre ash as a partial replacement material for concrete production.
- (vi) Based on the compressive flexural strengths results, *Costus englerianus* bagasse ash or bagasse fibre proved to be a promising partial replacement material for cement and hydrated lime in concrete. However, the performance of *Costus englerianus* bagasse ash or bagasse fibre will be enhanced as a partial replacement of cement than hydrated lime. Therefore, it has been recommended that the use of *Costus englerianus* bagasse ash or bagasse fibre up to 10% in the cement concrete or lime concrete provides good results for application in civil engineering.

Data Availability

The datasets produced during the proposed investigation are accessible from the authors upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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