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Effect of Guinea Corn Husk Ash (GCHA) on the compressive strength and water absorption of mortar

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ABSTRACT

In this research work, the weight loss, compressive strength, and water absorption of samples of cured mortar are measured to assess the effects of adding a 2% increment of GCHA content into the mortar mixture as a partial replacement of cement to determine how this addition affects the strength and other physical properties of the mortar samples produced. Compressive strength, slump, and water absorption tests were conducted according to BS EN 12390-3 (2009), BS EN 12350-2 (2009), and BS 1881-122 (2011) respectively. The results show that adding GCHA into mortar mix improves the mortar's strength up to 4% replacement level before it starts to decline. Moreover, adding more GCHA to mortar increases the mortar slump and water absorbance while density decreases. In addition, the study also reveals that GCHA-containing mortar is easier to handle than the control sample. These findings collectively support the potential of incorporating agricultural waste material in construction practices to achieve environmentally sustainable and durable building materials.

Keywords: Mortar; Guinea Corn Husk Ash; Cement; Compressive Strength; Water Absorption.

Graphical abstract

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1. Introduction

The use of agricultural waste materials as partial replacements for cement in mortar production has gained significant attention due to its potential to enhance the mechanical properties and sustainability of the resulting material. Several studies have investigated the effects of incorporating various agricultural waste materials, such as guinea corn husk ash (GCHA), rice husk ash (RHA), corn husk ash, and sugarcane bagasse, into mortar and concrete mixtures. These studies have demonstrated that the addition of these waste materials can improve the compressive strength, flexural strength, and durability of the resulting mortar.

For instance, Aburime et al. [1], Ndububa and Yakubu [2], and Odeyemi et al. [3] investigated the effect of GCHA as a partial replacement of cement in concrete to improve the compressive strength, workability, and durability of concrete. Also, Samson et al. [4] researched the use of guinea corn husk ash as an additive to improve the flexural and split tensile strength compared to traditional HPC. Further research was conducted by Samson [5] on the effect of GCHA on the compressive strength of lateritic concrete. These investigations show that GCHA has the ability to improve the mechanical properties of concrete.

Alex et al. [6] and Mehdizadeh et al. [7] investigated the influence of alumina nanoparticles and RHA on the partial replacement of cement to enhance the mechanical properties and durability of mortar. Similarly, Saand et al. [8] and Thiedeitz et al. [9] focused on the use of rice husk ash as a partial replacement for cement in concrete and mortar production, highlighting its effects on density, compressive strength, and split tensile strength. These studies collectively support the potential of RHA in enhancing the mechanical properties of mortar.

Furthermore, Odeyemi et al. [10] and Raheem et al. [11] explored the use of guinea corn husk ash and corn husk ash as partial replacements for cement in concrete and interlocking paving stones, indicating the broader applicability of agricultural waste materials in construction materials. Additionally, Sakib et al. [12] and Zhang et al. [13] investigated the impact of RHA on the mechanical characteristics and freeze–thaw resistance of recycled aggregate concrete, further emphasizing its potential to enhance the durability of concrete mixtures.

Various methods are used around the world to improve the quality of concrete and extend its durability, examples of such works are [14], [15]. Moreover, studies by Horák et al. [16] and Sam [17] provided insights into the chemical composition and properties of ashes from the corn grain drying process, highlighting the potential of various agricultural waste materials, including rice husk ash, in sustainable construction practices. These findings collectively support the potential of agricultural waste materials, particularly guinea corn and rice husk ash, in improving the mechanical properties and sustainability of mortar and concrete.

The utilization of agricultural waste materials, such as guinea corn husk ash, as partial replacements for cement in mortar production has shown promising results in enhancing the mechanical properties and sustainability of the resulting material. These findings underscore the potential of incorporating agricultural waste materials in construction practices to achieve environmentally sustainable and durable building materials. Previous researches have focused on 5-10% replacement levels of cement with agricultural waste materials such as RHA and GCHA, investigation has not been carried out to evaluate the effect of GCHA in mortar when added at 2% intervals. Hence, this research aim to investigate the performance of guinea corn husk ash when used to partially replace cement at 2% increment level in mortar production, with a focus on enhancing the mechanical properties and workability of the resulting material.

2. Materials and Methods

2.1. Material

The following constituents were used in the research project: water, fine aggregate, Guinea corn husk ash (GCHA), and ordinary Portland cement (OPC).

Cement: The hydraulic binder used in this study project was Dangote 42.5N Ordinary Portland Cement (OPC), which conforms with British Standard 12 [18]. It was bought at the Rimin Gata Town Market in Kano, Nigeria's Kano state capital.

Fine Aggregates: The fine aggregate was obtained from Rimin Gata town in Kano. Sieve analysis and specific gravity tests were performed on this material in accordance with British Standard 812 [19].

GCHA (Guinea Corn Husk Ash): The GCHA utilized in this study was obtained from the Dawanau market in Kano and burned in a rotating kiln at 600^oC at the mechanical engineering department at BUK. The following stages are involved in the preparation of Guinea Corn Husk Ash for use as a partial replacement for cement in mortar:

1. Sourcing of Guinea Corn Husk (GCH): This material were collected from Dawanau market in Kano state.
2. Cleaning: All debris from the material was removed to ensure it is free of other impurities.
3. Burning and Grinding: The GCH material was cremated in a rotary kiln at 600^oC for roughly two hours. The ash was collected, pulverized into powder, and sieved through a sieve with a mesh size of 150m. This investigation only used guinea corn husk ash that passed through a 0.0015mm sieve (Sieve No. 100).

Water: The water used in this study project was obtained from BUK's Civil Engineering Laboratory and met the specifications of British Standard EN 1008 [20].

2.2. Methods

2.2.1. Test on cement

The following tests were conducted on the cement material: specific gravity per American Standard Testing Method C188-17 [21], initial and final setting time per British Standard EN 197-1 [22].

2.2.2. Test on Fine aggregate

The tests conducted on the fine aggregates used in this research work are: specific gravity as specified in BS 812-1995 [19], sieve analysis per BS 812-103.2 [23], and bulk density per British Standard 812-3 [24]. The bulk density is found to be 1602 kg/m^3, and the specific gravity of the fine aggregate is 2.61. The fine aggregate used in this research is classified as zone-1 based on British Standard 882 - Part 2 [25].

2.2.3. Mixing process of fresh Mortar

Table 1 shows the ratios of cement, fine aggregate, water, and guinea corn husk ash (GCHA) derived from the mix design.

Table 1. Material ratio from mix design

Mix	OPC (g)	GCHA (g)	Fine Agg. (g)	Water (g)
A (0% GCHA)	636.28	-	4220	354.10
B (2% GCHA)	624.65	14.32	4220	343.84
C (4% GCHA)	610.08	27.05	4220	338.30
D (6% GCHA)	597.39	37.97	4220	331.15
E (8% GCHA)	586.85	52.66	4220	324.36
F (10% GCHA)	570.18	65.95	4220	316.92

2.2.4. Compressive Strength Test on Mortar

In compliance with the guidelines of British Standard EN 12390 Part 3 [26], compressive strength test was carried out on samples of hardened mortar containing varying concentrations of guinea corn husk ash at 0%, 2%, 4%, 6%, 8%, and 10% . The 72 samples were cured by fully submerging them in the water at the BUK Civil Engineering Laboratory's water tanks. After curing, the samples' compressive strength was assessed at 0, 3, 7, and 28 days. The testing was carried out at a loading rate of 35 kN/sec using the 2000 kN Avery Universal Testing Machine, 18 cube samples were tested for each curing period (0, 3, 7, and 28 days – 3 samples for each curing period). The testing was carried out in the concrete laboratory of the Civil Engineering Department, BUK. The compressive strength of each sample was determined using the following formula:

$$\text{Compressive Strength (N/mm}^2) = \frac{\text{Normal Load (N)}}{\text{Area of Specime (mm2)}} \times 100 \qquad (1)$$

2.2.5. Water Absorption Test on Mortar

Following the guidelines outlined in British Standard 1881-Part 122 [27], the water absorption test was conducted on a total of eighteen samples at the Department of Civil Engineering's concrete laboratory. The samples were dried in an oven for 72 hours, then removed and allowed to cool for a full day. Following their weighting, the samples were immediately submerged in water for a full day. Afterward, the excess water was wiped off with a cloth, and the samples were weighed again. The formula below is used to determine the water absorption of each sample.

$$\text{Water absorption (\%)} = \frac{\text{Weight of sample immersed in water} - \text{Weight of dry sample}}{\text{Weight of dry sample}} \times 100 \qquad (2)$$

2.2.6. Flow Chart

The flow chart below shows the experimental procedure (Fig 1) followed for the production and testing of the mortar samples (Fig 2). The flow chart shows that six different mixtures incorporating guinea corn husk ash (GCHA) at different proportions, 0%, 2%, 4%, 6%, 8%, and 10%. Slump test was conducted on the fresh mixture to determine its workability, while compressive strength testing was conducted at 0, 3, 7, and 28 days for every mixture. In addition, water absorption testing of the hardened mortar was performed at 28 days for each mixture. Plates (1-5) show some of the events during the experimental work.

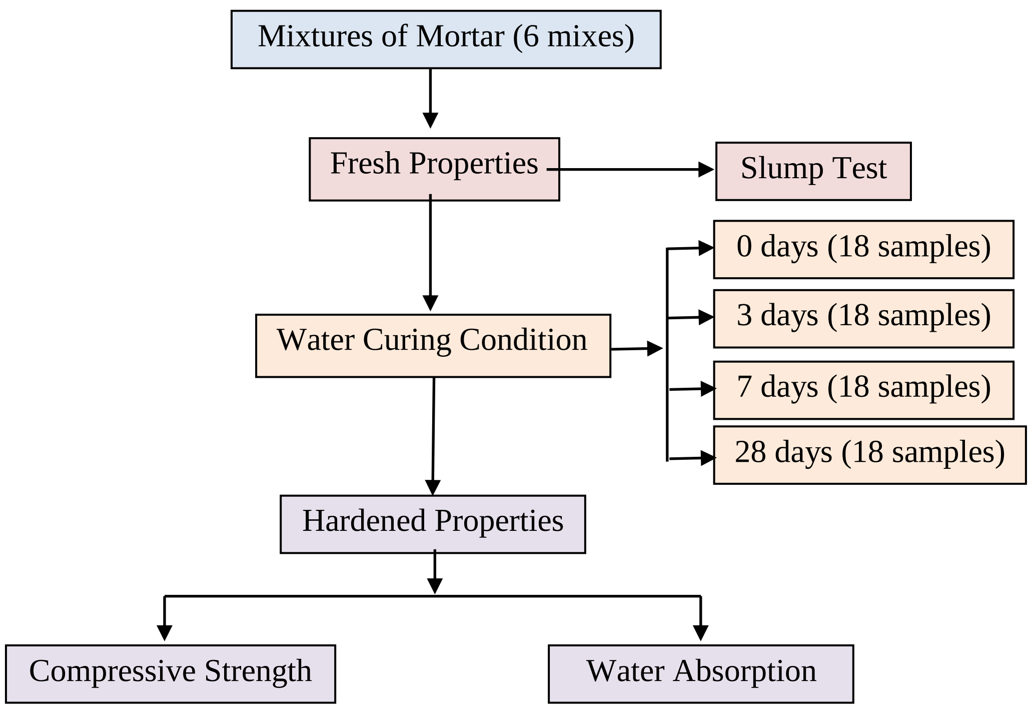

Fig 1. Flow chart of experimental procedure

Plate 1. Guinea Corn Husk

Plate 2. Guinea Corn Husk Ash fired up to 600^{o}C

Plate 3. Mortar Cube samples

Plate 4. Curing of mortar samples in water

Plate 5. Testing of mortar samples

Fig 2. Production and testing of the mortar samples

3. Results and Discussion

3.1. Preliminary Test Results

Table 2 and Table 3 below, respectively, exhibit the results of preliminary tests conducted on cement and fine aggregate materials. The outcomes met the requirements and followed the necessary code guidelines.

Table 2. Results of tests on cement

Test	Test Result	Specification	Code
Specific Gravity Test	3.15	3.10 – 3.16	ASTM C188-17 [21]
Initial setting time of Cement Test	69 min	Not < 45 min	BS EN 197-1 [22]
Final setting time of cement	380 min	Not > 6.5 hours (390 min)	BS EN 197-1 [22]

The tests provide an indication of the material's qualities, which will undoubtedly be reflected when the ingredients are blended in the mortar mixture. The sieve analysis result is presented in Figure (3).

Table 3. Properties of fine aggregate

Test	GCHA	Fine aggregate	Specification
Water absorption (%)	6.15	9.2	ASTM D570 [28]
Bulk Density (kg/m^3)	363	1612	BS 812-3 [24]
Specific Gravity	1.78	2.63	BS 812-103 [19]

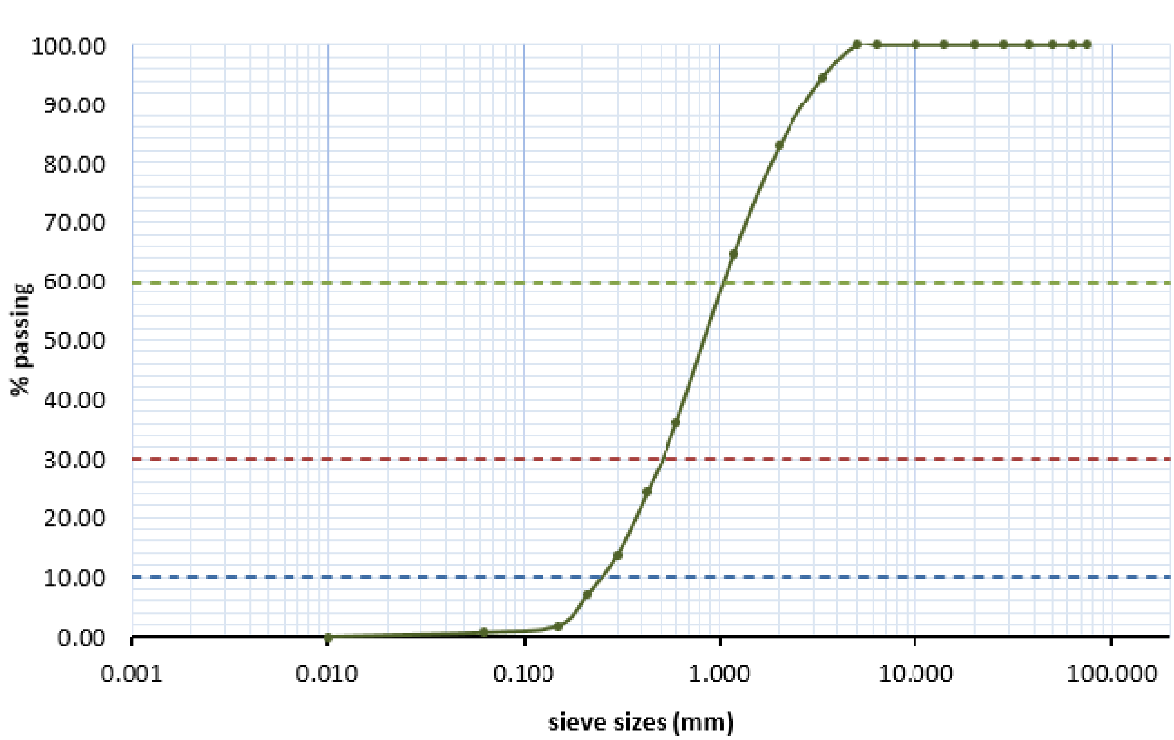

Fig 3. Graph of sieve analysis for fine aggregates

3.2. Slump Test Result

The slump test was carried out according to BS EN 12350-2 [29]. The results of slump tests performed on a new mortar mixture with 0–10% Guinea corn husk ash replacement are shown in Figure 4. The outcome showed that the slump decreases as the percentage of GCHA increases. At 8% GCHA replacement, when the slump decreases from 22.5 mm to 19 mm, the highest decrease of 18.4% was observed. The results demonstrate that GCHA-containing mortar is less easier to handle compared to the control sample. The decrease in slump may have been caused by the guinea corn husk ash's high cohesive capacity in binding with other materials and its ability to fill more pore spaces in the mixture.

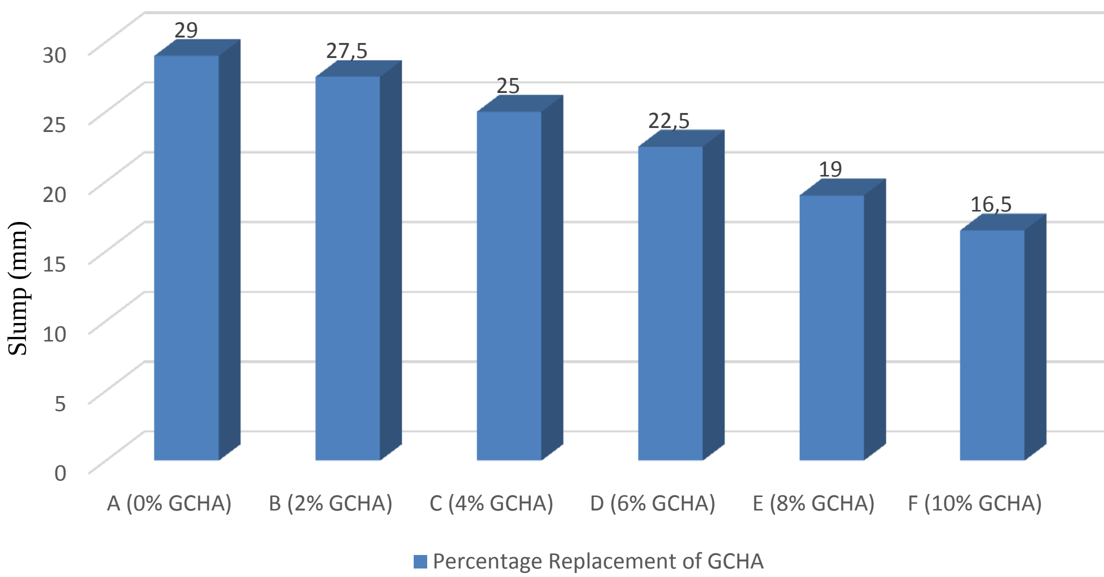

Fig 4. Slump test on mortar specimen

3.3. Compressive Strength Test Result of Mortar

Figure 5 shows the results of the compressive strength test carried out on mortar incorporating guinea corn husk ash. The mixes incorporating 4% GCHA yielded the highest strength at 0, 7, and 28 days, while the mixes with 6% GCHA showed the highest strength at 3 days. In comparison with the control samples, the mixes with 2% and 4% GCHA yielded improved strength for all curing days, while mixes with 6% and 8% GCHA yielded lesser strength only at 28 days. At 28 days, a maximum increase in strength of 7.5% was realized at 4% GCHA addition, when the strength increased from 10.04N/mm^2 to 10.59N/mm^2. On the other hand, mixes with 10% content of GCHA yielded lower strength than the control samples for all curing periods. As expected, the presence of GCHA in the mixture has significantly improved the compressive strength performance of the mortar samples. This conclusion corresponds with [2,4,5,30]. They investigated the effect of incorporating GCHA on the compressive strength of mortar, and found out that adding GCHA resulted in an overall performance of the mortar in terms of compressive strength.

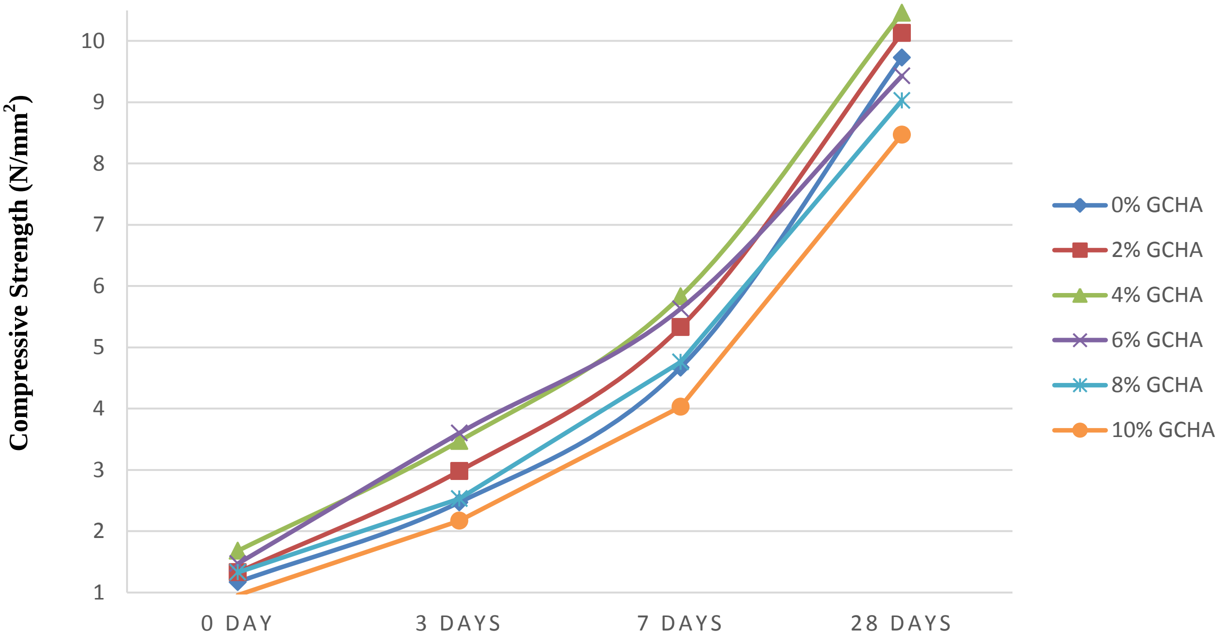

Fig 5. Compressive strength of mortar

3.4. Weight reduction

Figure 6 shows the weight reduction of mortar cube samples that contains guinea corn husk ash. The result shows that the mixes with GCHA yielded a decrease in the weight of samples as the content of GCHA increases, although a significant increase in weight of samples were observed with an increase in curing days. At 28 days of curing, a maximum decrease of 6.7% was observed at 10% replacement, when the weight was reduced from 2158 kg/m^3 to 2020.5 kg/m^3 compared to the control sample. It is expected that there will be slight reduction in the weight of samples with an increase in GCHA content. The result of this findings agrees with Oyedepo et al., [30] and Odeyemi et al., [31], they investigated influence of GCHA on the mechanical properties and density of mortar samples, and discovered that the density of the mortar decreases with an increasing level of GCHA content. The result reveals that light-weight mortar with significant strength can be achieved by incorporating GCHA into mortar mixes.

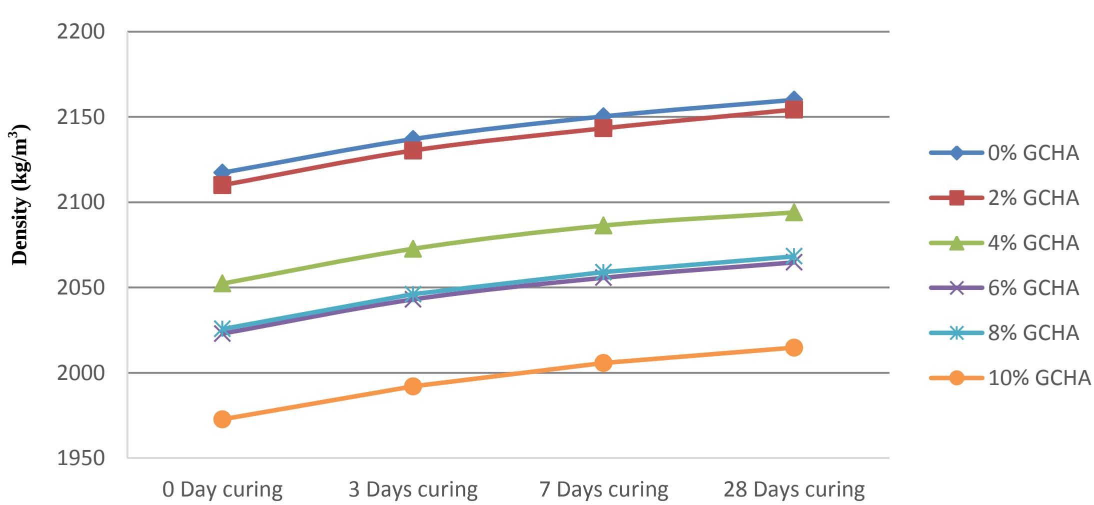

Fig 6. Weight of mortar with different percentage replacement levels of GCHA

3.5. Water Absorption of Mortar

Figure 7 shows the water absorption rate for each percentage replacement level of cement with GCHA content. From the result below, it can be shown that an increase in GCHA content increases the water absorption rate of the mortar samples. A maximum increase of 10.25% was observed at 8% addition of GCHA when the rate of water absorption increases from 7.6% to 9.3%. The rate of water absorption is expected to increase with the incorporation of GCHA content to the mixes. This is due to the ability of guinea corn husk ash to react with calcium hydroxide to form additional cementitious compounds that creates a more porous and interconnected network of voids within the mortar. This result agrees with the findings of Oyedepo et al., [30] and Smith et al. [32] from their investigation on the effect of GCHA on the mechanical properties and workability of cement mortar, the results from their research showed an improvement in water absorption as the percentage of GCHA added to the mixes increases.

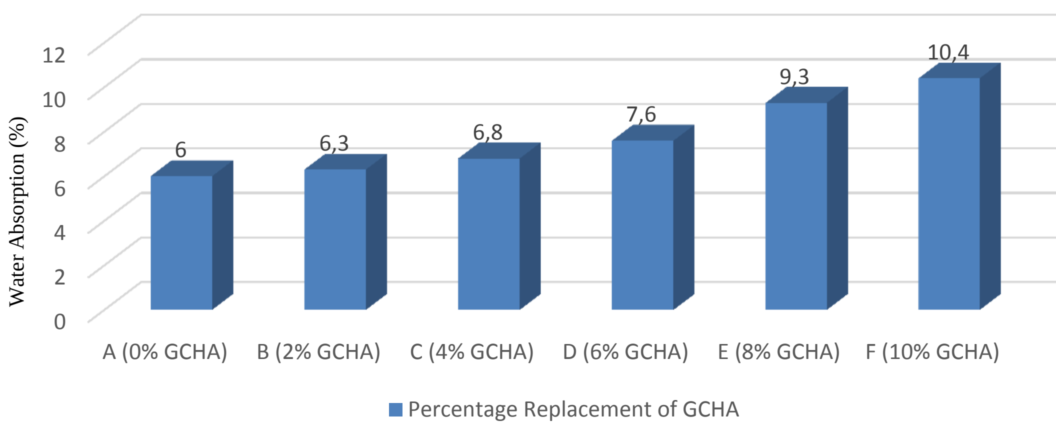

Fig 7. Water absorption vs percentage replacement of GCHA.

3.6. Failure mode

Figure 8 below shows the failure mode of the tested mortar samples. The failure modes of mortar from the compressive testing shows there was a brittle failure mode in all the mortar specimens. The percentage of guinea corn husk ash that was added to the mortar samples (0–10%) did not reduce the brittle failure under compressive stress. This phenomenon demonstrated that adding guinea corn husk ash does not increase mortar's toughness.

Fig 8. Failure mode of the mortar samples

4. Conclusion

In this research work, an investigation was carried out to evaluate the effect of adding guinea corn husk ash (GCHA) content into the mortar mixture as a partial replacement to determine how this addition affects the strength and other physical properties of the mortar samples produced. The following conclusions were drawn from these research findings:

1) Increase in the percentage of GCHA added to the mix yields higher slump value. The highest percentage increase was observed at 8% GCHA.
2) At 4% addition of GCHA, maximum strength was observed at 0, 7, and 28 days.
3) Increasing the percentage of GCHA in mortar mix leads to reduction in weight of mortar produced.
4) When GCHA content is increased in the mix, the rate of water absorption of mortar also increases. Maximum increase of 10.25% was observed at 8% addition of GCHA.
5) The mode of failure of tested hardened mortar samples is brittle in nature. Increasing GCHA content in mortar mix does not improve the toughness of the hardened mortar.

The long term effect of guinea corn husk ash on the strength and durability of mortar can be investigated.

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Ethical Statement

This study does not contain any studies with human or animal subjects performed by any of the authors.

Conflict of Interest

The authors declare that they have no conflict of interest.

Data Availability Statement

Not applicable.

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