Strength Evaluation of Acha Husk Ash Concrete Blended with NBRRI Pozzolana

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Abstract: Following the increasing need for sustainable construction materials, this study explores the potential use of Acha (Fonio) Husk Ash (AHA) as a partial replacement for cement in concrete production. AHA, derived from the agricultural waste of Fonio grain processing, was incorporated into concrete at replacement levels of 5%, 10%, 20%, and 30%. The research also evaluates a 50:50 blend of AHA with Nigerian Building and Road Research Institute (NBRRI) pozzolana to enhance the mechanical properties of the concrete. The experimental program included standard tests such as compressive strength, slump test, and density measurements with different water/cement ratios. Compressive strengths were measured at curing intervals of 7, 14, 28, and 56 days. At 28 days, the concrete with 5% AHA replacement demonstrated a compressive strength of 31.11 N/mm^2, outperforming the control mix (28.08 N/mm^2). The 20% AHA mix also performed well, achieving 27.65 N/mm^2 at 28 days and 31.37 N/mm^2 at 56 days. However, the 30% AHA mix showed reduction in strength, with 22.70 N/mm^2 at 28 days and 25.03 N/mm^2 at 56 days, indicating that higher replacement levels may hinder strength development. When blended with NBRRI pozzolana, the concrete demonstrated slower early-age strength development but exhibited continued strength growth over time, showing potential for non-structural applications. Slump tests revealed that increasing AHA levels slightly reduced the slump, indicating a need for additional water to maintain the desired consistency. This study highlights AHA as a viable supplementary cementitious material that can reduce cement consumption, lower environmental impact, and offer a waste-to-wealth solution in the construction industry. Furthermore, optimization is recommended to improve early-age strength and expand its applicability in structural concrete.

Keywords: *Acha (Fonio), Husk Ash, NBRRI Pozzolana, Strength Evaluation.*

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I. INTRODUCTION

According to Matawal (2023), Conventional Cement is a fine powder created from crushed limestone and clay which acts as a glue-like binder to hold the Concrete ingredients together. On the other hand, Concrete is the finished product that results from mixing fine/coarse aggregates, water, admixtures, and cement together. The Roman Empire was the first civilization that used concrete for building houses from a mix of pumice, pozzolana, and lime to make concrete. The largest concrete dome that was built in 120 A.D. is the former Roman temple, Pantheon in Rome. Concrete comes in varying strengths and appearances and is typically made from 4 key ingredients, which we must distinguish from the chemical compounds that form cement and are critically influential to its inherent properties and behavior. These include:

- Water: the most crucial element of concrete is water. The quality of concrete is determined by how much water is used. Water creates a chemical reaction when it comes into contact with cement. It also aids workability as long as the right ratio of water to cement is used.
- Cement: this is the binding ingredient that holds all the materials together.
- Fine and coarse aggregates: sand and stones
- Admixtures: other than cement, water, and sand, admixtures are also used before or during the mixing process. Some examples of admixtures include silica fumes, slags, and water reducers.

Therefore, with the established and old-age practice and reliance on Cement and Concrete, it will be surprising that there can be any doubt about its use.

However, growing public concern over existing and potential impacts on environmental quality, surface and ground water resources, and public health resulting from wastes, especially agro-wastes, has been expressed in the past and rising to a crescendo. In Nigeria, agricultural waste generation is raising fast and often creates huge wastes disposal and management challenges. The very reason for this

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is the spiraling growth in population with accompanying urban expansion (Ojolo et al., 2007). For this reason, there are increased demands for housing and construction instigating high demand for cement, the basic binder in concrete, leading to increased costs of cement and rising environmental concerns, cement and concrete being on the higher chain of carbon imprint materials. Hence, the search for alternatives or partial replacements for cements has led to attention shifting to agro-wastes and other products with potency to become cementitious materials.

However, for many years now there has been intense interest in the use and application of pozzolans to replace partially or wholly in concrete and mortar production. Massazza (2003) asserts that the use of pozzolanas has been mostly long and well embraced in Italy, where considerable reserves of natural pozzolanas are found and to Greece (Santorin earth). Apart from that, in most countries of the world, the interest in these materials is of relatively recent date and has arisen from the need for reusing some waste materials such as fly ashes and Silica fume. In any case, results of a variety of studies have substantially confirmed that pozzolanic cements can yield concrete showing a high ultimate strength and great resistance to the attack of aggressive agents. Kiran and Ratman (2014) noted that cement production gives rise to CO_2 emissions generated by the calcinations of $CaCO_3$ and by the fossil, being responsible for about 8% of the CO_2 emissions in the world. This can be substantially reduced if cement replacement materials such as a fly ash are used within the frame work of comprehensive research concerning this residual of coal industries and so they studied some durability characteristics of concretes made with Fly ash. Dixit and Kushwaha (2021) in their own study, noted that concrete is the most widely used construction material in the world it is a mixture of cement, sand, coarse aggregate and water. Storage and safe disposal of industrial by product such as fly ash, Sisal Fiber and rice husk ash was a huge problem everywhere, reuse of these waste eliminates/reduce the problem. Matawal D. S. and Aliyu Sani, et al (2019) evaluate the behavior of high-performance concrete (HPC) containing mineral admixtures.

Muangtong, Sujjavanich and Poomiapiradee (2013) investigated the effects of fine Bagasse Ash on the workability and comprehensive strength of mortars. The study based in Thailand, noted that there are various kinds of agricultural waste ashes throughout the industrial processes in their country such as sugar cane bagasse ash (SCBA), rice husk ash, oil palm ash etc. They are currently exploited as pozzolanic materials and supplements to improve the compressive strength in terms of microstructures of cement by part-replacement of cement with them. One of their advantages is to decrease CO_2 gas emission from decreasing consumption of cement in either mortar or concrete production.

Opeyemi and Matawal, et al (2018, noted that Portland Cement (PC) is currently the world most commonly used binder in mortar/concrete applications. PC-based concrete is the world’s most consumed manmade material and consequently puts lots of demand on cement as a binder. PC was later discovered to be non-environmental-friendly material due to its green house (carbon dioxide, CO_2) gas emission mainly during production, which contributes greatly to global warming and all its negative impacts worldwide. Concrete production contributes up to 5% of the annual global CO_2 emissions of which the bulk is from the production of cement. Other factor debilitating the use of PC is its high cost which further translates to the cost of mortar/concrete-based structures as buildings, making housing less affordable for the citizenry. These PC concerns have led to the development of greener and cheaper alternative binders which have so far evolved the PC to blended and pozzolanic cements.

Despite its rich cultural heritage and nutrient profile, Fonio is considered a neglected and underutilized crop species. Sometimes referred to as “lost crops,” “minor crops,” or “orphan crops,” these family of crops have needs to be more thoroughly researched, are utilized poorly, and largely grown by smallholder farms. Yet, this tide is changing. Today, Fonio is listed as a priority crop for West Africa. Due to its nutritional and environmental properties, as well as its potential to diversify one’s diet, it can be found in specialty food aisles and stores across the world. Furthermore, fonio has become an important source of income for smallholder farmers in West Africa. The acha used for this project was sourced in Jos coming as waste of acha processing from farms in Bokkos, Barkin Ladi, Jos South and other areas, including Bauchi and Kaduna states.

Acha waste, Fonio straw and fonio husks are often left to rot on the field or burned, causing soil and air pollution: the use of these crop residues for fodder, compost or organic fertilization, or other industrial uses could limit these negative effects. Attempts have been made to process the Fonio/Acha Husk Ash (AHA) as a pozzolana for partial replacement of cement in the production of mortar and concrete. This project will conduct, as its main experiments, the replacement of cement is in different proportions with AHA and then based on 56-days observation of strength development, the percentage replacement that yields optimal cube compressive strength replacement will be re-proportioned 50-50 with NBRRI pozzolana obtained from Bokkos pozzolana pilot plant and a batch of concrete processed for tests to observe the effect on the strength of the resulting concrete.

The study is prove to be right by the growing concerns regarding the environmental impact of cement production, including CO_2 emissions and resources depletion. Cement is a major contributor to greenhouse gases, and with its high cost, there is a pressing need for alternatives. Agricultural waste, such as Acha (fonio) husk ash (AHA), is abundant and often discarded, causing environmental pollution. Utilizing AHA as a partial cement replacement aligns with sustainable construction practices by reducing waste and lowering cement dependency. This study aims to explore a viable “waste-to-wealth” opportunity while potentially offering more affordable housing solutions for Nigeria.

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II. MATERIALS AND METHODS

➢ *Materials*

The materials used for this study include: Acha (fonio) Husk Ash (AHA), Fine and Coarse Aggregates, NBRRI Pozzolana, Ordinary Portland Cement (OPC) and Water. The sources of the Acha (fonio) are from farmers in Bokkos, Barkin Ladi, Jos south and other sources from Plateau, Bauchi and Kaduna states. Both the quarry dust and the coarse aggregates (12mm and 19mm combined in a ratio of 50:50) were obtained from the TRIACTA industrial quarry located at Bayara village of Bauchi town. NBRRI Pozzolana was obtained from Bokkos NBRRI Pozzolana Pilot Plant Plateau State. The chemical analysis of the NBRRI Pozzolana was conducted at the laboratory of Umaru Musa Yaradua University, Katsina, using the X-Ray Diffraction Analyzer (XRF test) equipment.

Ordinary Portland Cement of Dangote 3X was used for the experiments and procured from cement vendors in Bauchi. Clean Tap water from Structural Laboratory of Department of Civil Engineering ATBU Bauchi was used, hence no test was conducted.

➢ *Methods*

The facilities in both soil mechanics and structures laboratories of the Department of Civil Engineering, Abubakar Tafawa Balewa University were used for all the laboratory experiments. A 1:1:2 straight forward mix by weight was used with a water to cement (w/c) ratio of 0.6 was used with the AHA and cement partial replacement levels applied by weight ratios. Total Number of Concrete Mixes = 6, Total number of Cubes = 90 at 15no per mix. Thus penultimately, a selected best mix was combined with a sample of NBRRI Pozzolana at a ratio of 50:50 and 12 cubes were produced and crushed at the given dates. This test indicated the effect of the Pozzolana on the mix and the best or optimal partial replacement level. Batching by weight and fresh samples were subjected to slump tests. Vicat apparatus method was used in determining the consistency and setting times of the AHA/Cement paste in accordance to BS1881. The compressive strength of the 90 cubes prepared using mix ratio of 1:1:2 and water-cement ratio of 0.6 was obtained in accordance to ASTM C33 test procedure. Three Cubes were tested for each replacement level and test age. An average of three was recorded as the compressive strength of the replacement level and the age. Density test is important in determining the weight of concrete and was carried out in accordance to BS 1881, Part 254 for each cube. Thus, at the end of each curing period, every cube was weighed using an accurate weighing machine balance after 24 hours curing and dewatering by removing from the curing tank before crushing. The averages of 3 samples were recorded. The strength development of mortar, concrete and other cement products depend on the presence of water for the hydration reactions of cement in concrete. Therefore, the concrete cubes were subjected to curing after demolding fully immersed in a clean water tank in the laboratory. The samples were dry up and re-measured their weighed before crushing in the compression machine.

III. RESULTS AND DISCUSSIONS

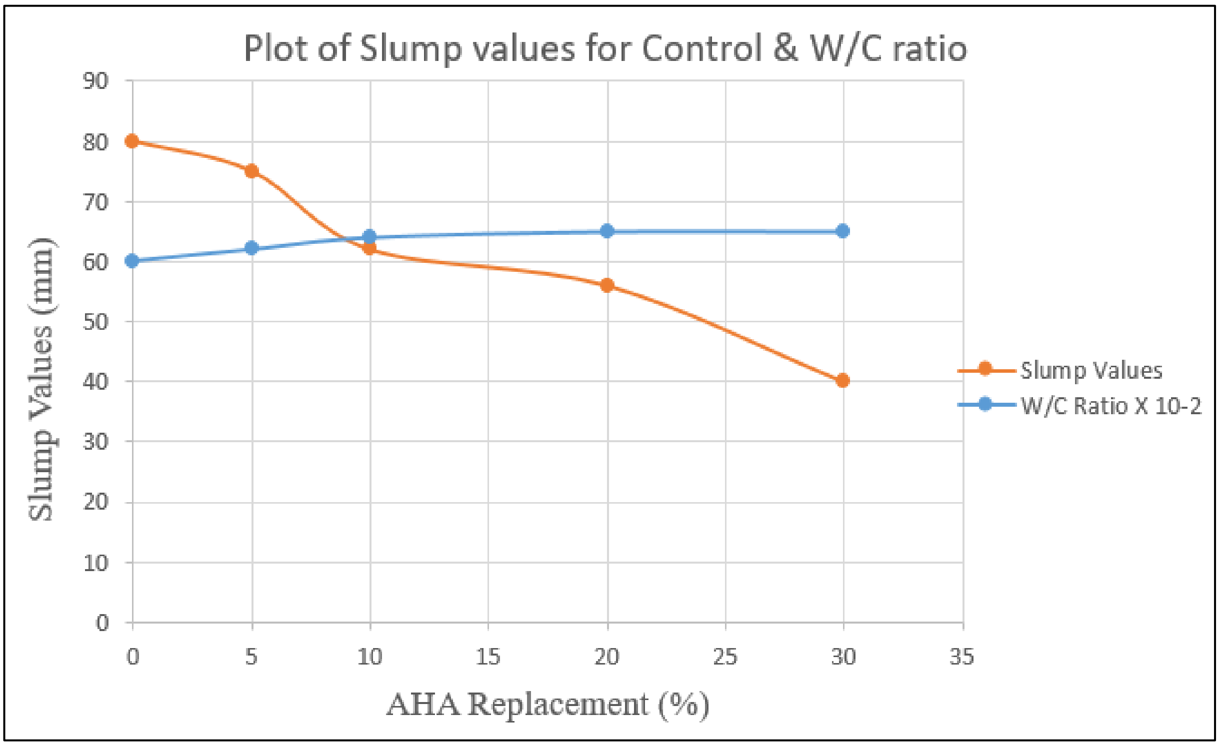

Fig 1 Variation of AHA Replacement Versus W/C Ratio and Slump Values

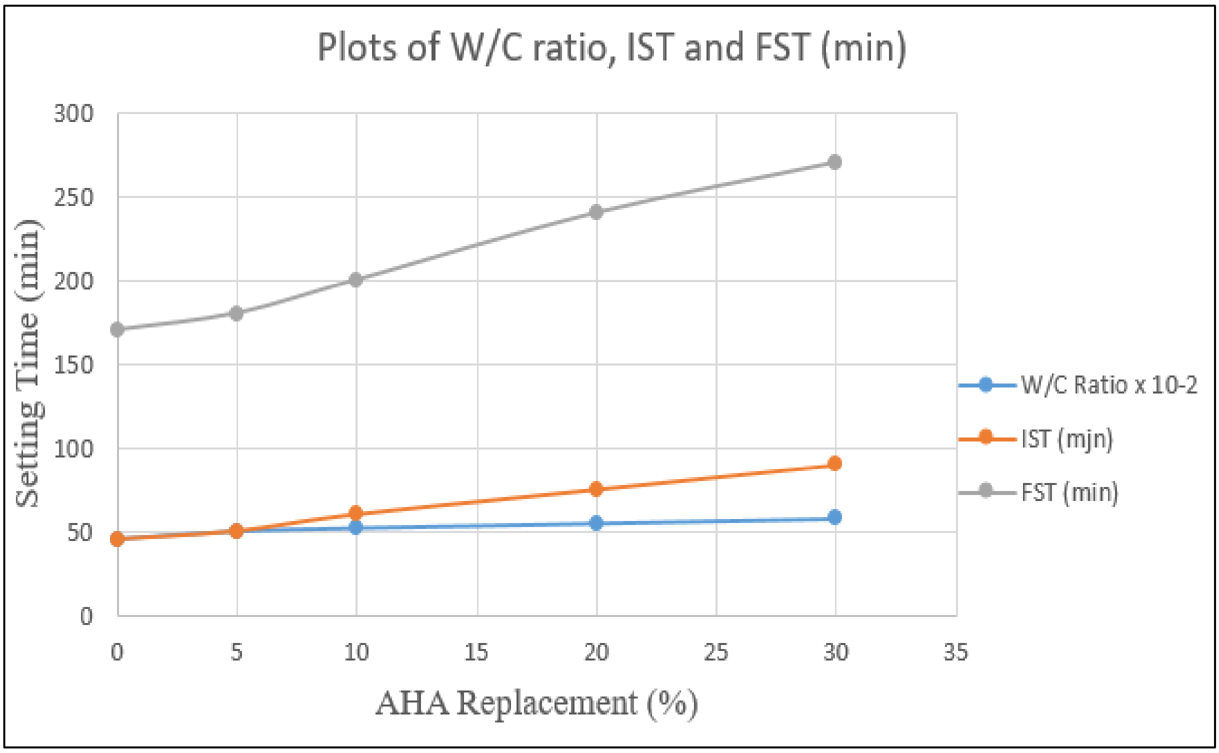

Fig 2 Variation of AHA Replacement Versus W/C ratio, ISTand FST (min)

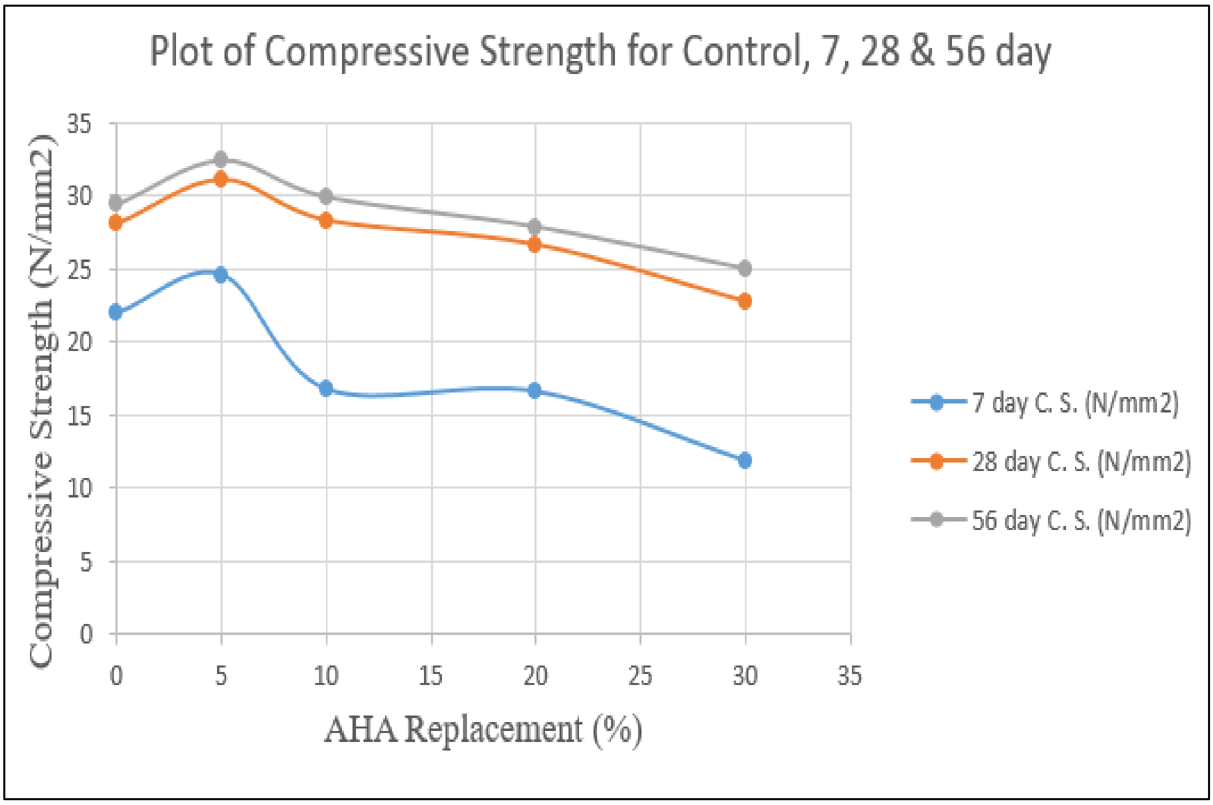

Fig 3 Variation of AHA Replacement Versus Compressive Strengths (N/mm2)

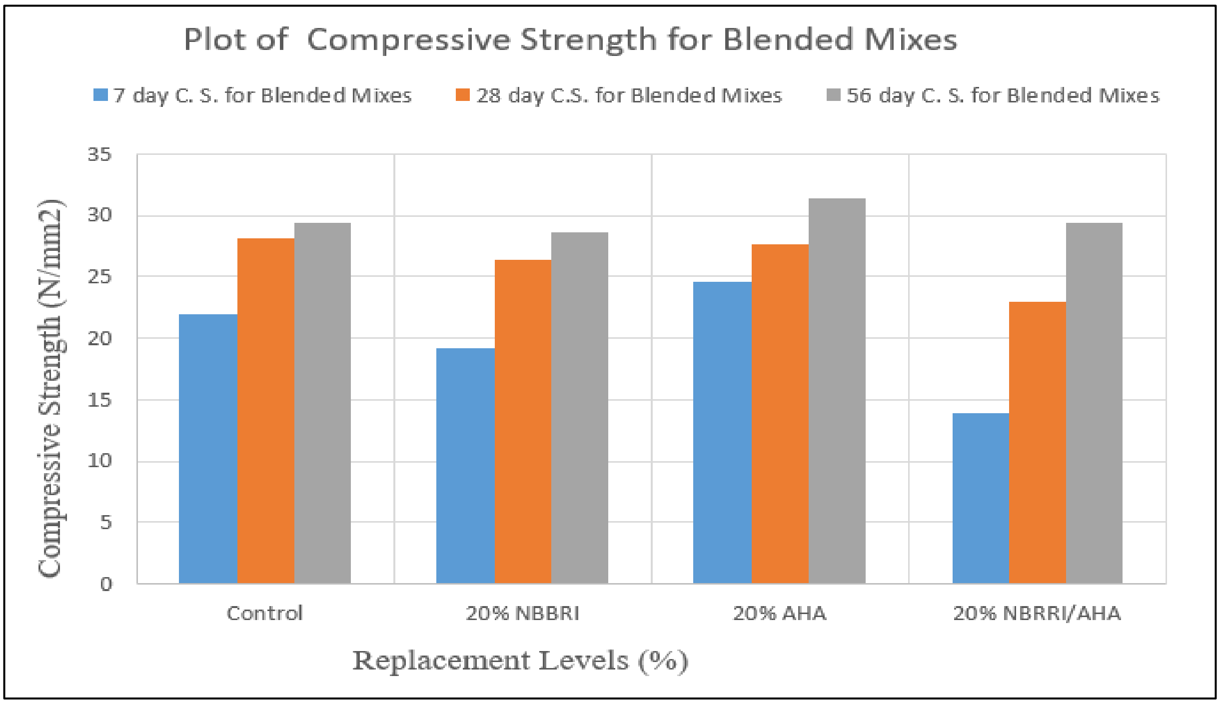

Fig 4 Variation of Replacement % Versus Compressive Strengths (N/mm2) for the Blended Mixes

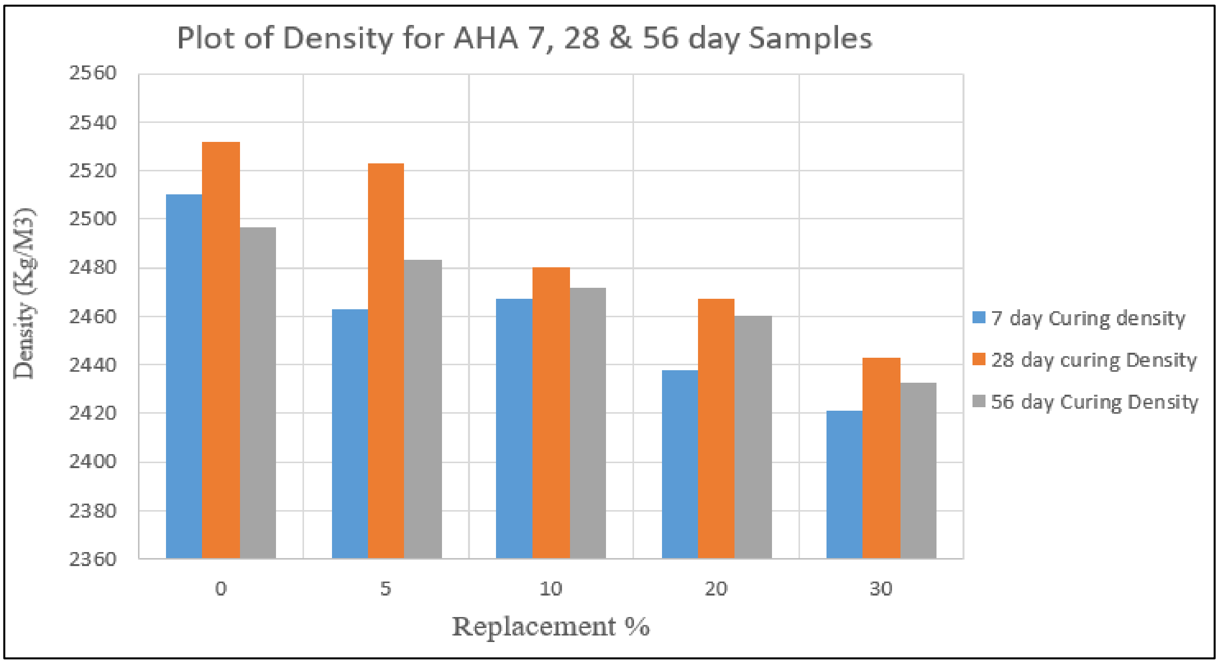

Fig 5 Variation of Replacement % Versus Densities for 7, 28 &56 Curing Age

➢ *Observations on AHA-Cement Concrete Compressive Strength (N/mm²) Results*

Figure 3 shows the variation of AHA replacement versus compressive strengths (N/mm2). At 7 day age, the control sample (0% AHA) shows a compressive strength of 21.96 N/mm². 10% AHA and 20% AHA resulted to reduced strengths of 16.77 N/mm² and 16.62 N/mm², respectively. However, 5% AHA demonstrates an increase to 24.57 N/mm², surpassing the control with about 12%. At 30% AHA, strength drops to 16.62 N/mm², indicating that higher levels of AHA hinders early strength development. At 28 day age, 5% AHA gives the best result of 31.11 N/mm², which is higher than the control (28.08 N/mm²). 20% AHA continues to perform well at 28.32 N/mm², slightly higher than the control. 30% AHA again shows a reduction in strength (22.74 N/mm²), consistent with the trend of reduced strength at higher replacement levels. At 56 age, the control sample reaches 29.38 N/mm². 5% AHA and 10% AHA achieve the highest strengths of 32.37 N/mm² and 31.37 N/mm², respectively. 20% and 30% AHA, on the other hand, still shows a reduced strength of27.87 N/mm²and 25.03 N/mm² respectively, indicating that the strength improvement with increased curing time does not fully compensate for the higher ash content.

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Figure 4 shows the variation of replacement % versus compressive strengths (N/mm2) for the blended mixes. At 7 day age, the control sample (0% replacement) shows a compressive strength of 21.96 N/mm². The 20% AHA + NBRRI blend shows a much lower strength of 13.85 N/mm², reflecting a slower early-age strength gain when both AHA and NBRRI were used together in the mix matrix. At 28 day age, the control reaches 28.08 N/mm², while the 20% AHA + NBRRI blend rises to 22.90 N/mm². Although the blend improves in strength gain compare to 7 day age strength. It is still significantly lower than the NBRRI, AHA and the control samples. At 56 day age, the 20% AHA + NBRRI blend improves to 29.37 N/mm², though insignificantly lower than the control and AHA mixes, indicating that this combination's strength gain is delayed but continues to develop over time. It can be observed from the figure that the NBRRI only blended samples strengths are slightly lower than the control and AHA samples strengths by about 8% and 14% respectively, indicating that replacing NBRRI pozzolana along at 20% replacement level significantly improves strength development at early strength gain and over time.

- *Observations on AHA-Cement Concrete Density (kg/m³) Results*

The results for the densities of all the AHA-Cement concrete samples are depicted in figure 5. The density of the control mix remains high, ranging between 2510 kg/m³ and 2532 kg/m³ across the ages tested. This is expected, as the cement-only mix is typically denser than the most blend cement agro-waste pozzolana ash mixes as reported by several literatures recently. As the percentage of AHA increases in a mix, the density decreases slightly. For example, the 5% AHA densities ranges from 2423 kg/m³ to 2523 kg/m³. 10% AHA shows densities between 2467 kg/m³ to 2480 kg/m³. 20% AHA shows densities between 2438 kg/m³ to 2467 kg/m³. 30% AHA exhibits the lowest densities, such as 2420 kg/m³ to 2433 kg/m³. The lower density of the AHA-based concrete can be attributed to the high pozzolanic nature of the AHA ash, which typically produces a lighter material. The density of the 20% AHA + NBRRI blend ranges between 2407 kg/m³ and 2537 kg/m³. These densities remain somehow comparable to the control, but they are on the lower side at the early curing stages (7 to 28 days). This aligns with the lower compressive strength observed at early ages. The density of the blend increases over time, with the highest value observed at 56 days (2537 kg/m³), indicating continued material densification as the pozzolanic reaction progresses.

- *Observations on AHA-Cement Slump and Setting Times Test Results*

Figure 1 shows the effects of AHA content replacement on W/C ratio and slump values. The w/c ratio used for all the replacement level mixes ranges between 0.62 and 0.65 with 0.60 for the control. As the AHA content increases in a mix, the w/c ratio increases, indicating that water demand for AHA-Cement concrete mixes are high than the control by about 3% to 8%. This increase in the mixing water translates to decrease in compressive strength. The same figure depicts the slump values for all the mixes which range between 40mm and 80mm with the control having the highest value of 80mm. All the slump values fall within the plastic/medium (S3) class of workability according to BS 8500 and ACI 117 stipulations. The control and 30% AHA have the highest and lowest slump values of 80mm and 40mm respectively, indicating that the control mix can easily flow with lesser strength than the 30% AHA mix which can requires vibration that could result to higher strength.

Figure 2 depicted the effects of water/cement ratio, initial and final setting times on cement/AHA mixes. It can be observed from the graph that increase in the AHA content, proportionally both the water/cement ration and the setting times increases, indicating more AHA content resulted into higher water demand and longer setting times. Increase in water to maintain workable mix, setting time increases and drops in strength are observed. If the strength is the concern, water is kept low, dry mix, poor compaction and the mix slightly sets faster. Inferring, AHA/Cement mix behaves in a similar way like other agro-waste pozzolana ashes such as rice husk ash having high content of silica. If AHA calcined at 650ºC-700ºC, it sets faster and less retarder because organics are burn off and the high silica is reactive.

IV. CONCLUSION

From strength evaluation of Acha husk ash concrete blended with NBRRI pozzolana examination conducted it remained concluded that Acha husk calcined at temperature between 650^{OC} to $700^{O\ C}$ is pozzolanic in nature as it gives a value of 95.15% with the summation of SiO_2 (59.05%) + Al_3O_2 (33.18%) + Fe_3O_2 (2.92) according to BS 1881: Part 103 and ASTM C618-17, 2017. The study successfully demonstrated that AHA (Fonio) Husk Ash and NBRRI Pozzolan can be used as partial replacements for cement in concrete production without significantly compromising strength, especially at later curing stages. While the early-age compressive strength decreased with increased replacement levels, the performance at 28 days and beyond remained comparable to the control mix. This indicates that the combined use of AHA and NBRRI Pozzolan holds potential for reducing cement consumption and, by extension, lowering the environmental footprint of concrete production. Additionally, the study supports the viability of valorizing agricultural waste like fonio husk ash in sustainable construction materials. As further works are pursued over time, 20 percent AHA replacement levels can be used for mass housing bungalow type construction, 20 percent AHA – NBRRI Pozzolans can be used for rural housing. To maximize the strength potential of ACHA and NBRRI Pozzolan-blended concrete, further research should be conducted to optimize the mix proportions, focusing on achieving better early-age strength. To validate the laboratory findings, real-life field trials using ACHA and NBRRI Pozzolan-blended concrete should be conducted. These trials will provide insights into the practical applicability of the material in construction projects.

- *Authors Contributions Statement*

UAA conceived this experimental study and designed the experiments. UAA and MPM participated in the design and interpretation of the data. UAA & MPM performed

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experiments and analysis. UAA wrote the manuscript. UAA and MPM participated in the revisions of the manuscript. All authors read and approved the final manuscript.

➢ *Conflict of Interests*

The authors of this paper declared that no conflict of interests regarding its publication.

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