Adobe strength upgrade using inorganic polymer cement

Anigilaje Bunyamin SALAHUDEEN ▪ Department of Civil Engineering, University of Jos, Jos, Nigeria ▪ bunyamins@unijos.edu.ng
Yahaya Aliyu SHUAIBU ▪ Department of Civil Engineering, University of Jos, Jos, Nigeria

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Abstract

Those in developing nations who find it difficult to obtain conventional building materials because of their low personal incomes are especially affected by the ongoing price increases of conventional building materials. The purpose of this study was to examine alternative building materials for affordable housing. The research methodology involves evaluating in a lab the properties of 150 x 100 x 100 mm unburnt earth blocks that have been treated with rice husk ash (RHA) geopolymer cement (GPC). In order to test the compressive strength of the adobe blocks made with different amounts of clay/RHA geopolymer—0, 10, 20, 30, 40, 50, 60, 70, 80, 90, and 100 percent—they were crushed after 7, 14, 21, and 28 days of curing. As the percentage content of RHA-GPC increased, it was found that the block samples absorbed more water. A number of the block samples' engineering characteristics, including their thermal conductivity, water absorption rate, and presence of voids or cracks, were carefully observed. It was advised that up to 100% RHA geopolymer content can be used to replace cement by weight in light of the compressive strength result of 2.8 N/mm^2 at 28 days.

Keywords: earth block, geopolymer, construction material, strength improvement, cement replacement
Kulcsszavak: földtégla, geopolimer, építőanyag, szilárdságnövelés, cementhelyettesítés

Dr. Anigilaje Bunyamin SALAHUDEEN
was a Senior lecturer and researcher at University of Jos, Jos-Nigeria where this research was performed. He obtained his Doctor of Philosophy degree in Civil/Geotechnical Engineering from Ahmadu Bello University. He has co-authored over 80 publications and was certified as Civil Engineer by the Council for the Regulation of Engineering in Nigeria (COREN) in 2013. His research interests include problem soil stabilization using agro-industrial wastes, biomass and geopolymer cements; numerical modelling of geotechnical problems, geotechnical application of artificial intelligence and general computational geomechanics. He is presently researching on solid waste valorisation; alternative and sustainable construction materials, 3D printing and climate change challenges.

Mr. Yahaya Aliyu SHUAIBU
is a researcher and graduate of the Department of Civil Engineering, University of Jos where he obtained his Bachelor of Engineering degree in Civil Engineering. He currently works as a Site Engineer with Kairos Hof consultant Ltd. His research interest focus on improvement of earth blocks for sustainable construction. He has actively contributed to academic and professional engagements, including representing his faculty in an inter-faculty debate competition, where he emerged as the winner. He is an ambassador for industry advancements and best practices. Yahaya is also a member of the Nigerian Institution of Civil Engineers (NICE).

1. Introduction

Every nation recognizes the importance of providing people with high-quality, reasonably priced housing for their overall well-being. For this reason, natural resource-based building materials are frequently employed. Examples include utilizing river sand to create cement-sand blocks and clay to create bricks. Using sand resources for sandcrete blocks commercially frequently results in a number of environmental issues. Prolonged mining of sand can cause riverbeds to drop and brine to seep inland. To reduce the impact on the environment, it will be very beneficial to develop as many alternative wall materials as possible. There are chances to significantly cut down on energy use and carbon dioxide emissions by using a cement substitute material with less of an adverse effect on the environment.

There are several ways that walls can be constructed out of earth. Few unfavourable characteristics do exist, though, including poor dimensional stability, erosion from wind or rain, and strength and weight loss upon saturation. Using a chemical stabilizer like geopolymer cement to stabilize the soil can greatly reduce these drawbacks [1]. According to Salahudeen and Bakare [2], employing earth blocks has the advantage of lowering energy costs, greenhouse gas emissions, and overall production costs. The technology of compressed, stabilized clay blocks is an alternative to the conventional fired brick technology. It is significantly less expensive, makes use of locally available resources, uses less energy, and emits less CO_2 during production [1]. Compressed clay blocks, or CEBs for short, are the contemporary offspring of shaped clay blocks, or adobe blocks as they are more widely known. Comparing CEB to conventional earth building methods, there is a noticeable improvement. When quality control is maintained, CEB products perform comparably to other materials like burnt brick or sand-cement blocks [3].

The agricultural waste that results from milling rice is called rice husk. It is estimated that 600 million tons of rice are harvested annually worldwide. Global production of rice husks is estimated to be 100 million tons per year [4]. Nigeria produces about 2 million tons of rice a year, with 96,660 tons of rice grains produced in the country in 2000 alone [5 and 6]. About 20% of the weight of paddy rice is made up of rice husk, which has a composition of 50% cellulose, 25–35 percent lignin, and 15-20% silica [7 and 8].

An innovative research project and an environmentally friendly, effective, and sustainable solution will be the use of rice husk to increase the density of earth blocks and rice husk ash geopolymer cement to partially replace Portland cement in order to increase strength in both earth and concrete blocks and decrease water absorption of earth blocks. According to UN-IDOTM [9], soils intended for use in cement-stabilized clay blocks must contain 15% gravel, 50% sand, 15% silt, and 20% clay. The handbook states that for lime-stabilized clay blocks, the proportions should be 15% gravel, 30% sand, 20% silt, and 35% clay. The handbook also specifies that mud-stabilized blocks made for 4 and 7 MPa should be treated because they have a plasticity index of no more than 15 and 10%, respectively, and a cement content of 4–7% and 7–10% of the dried soil's volume.

Recent research into using agro-industrial waste products as a partial replacement for cement has led to the discovery of potential cementitious materials from biomass ash. Among other materials, these include sawdust, peanut shells, rice husks, and corn cob ash [10-13]. The results of these studies

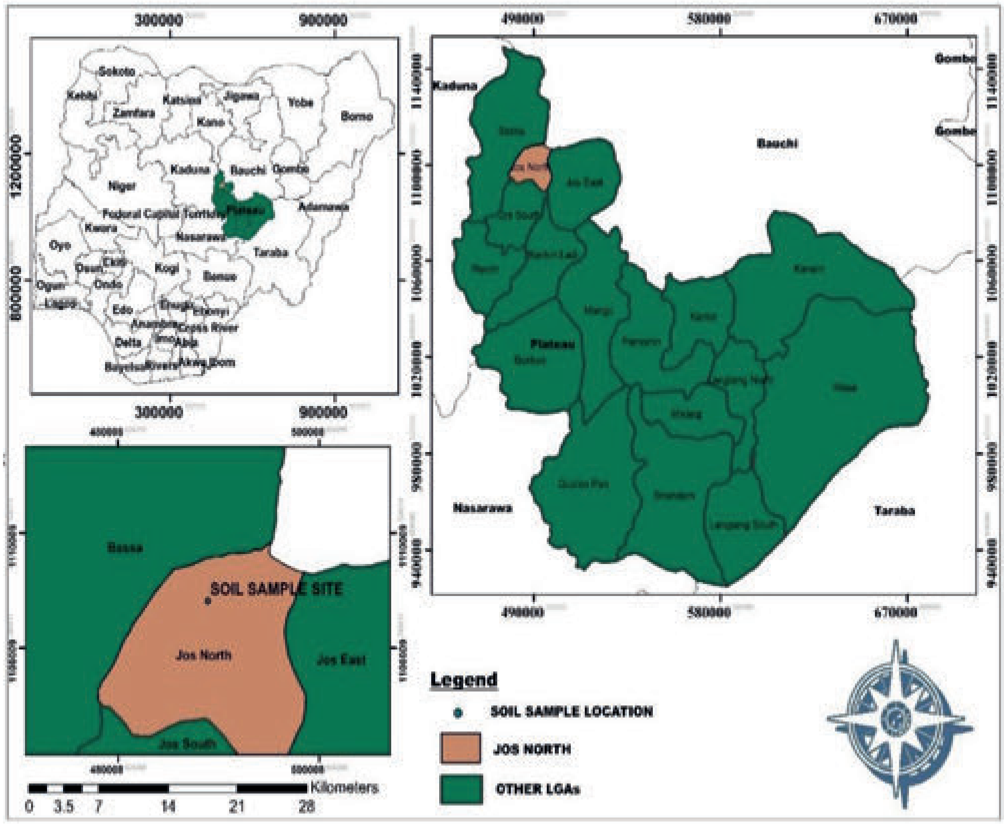

Fig. 1 Location map of soil sample site
1. ábra A talajmintavételi hely térképe

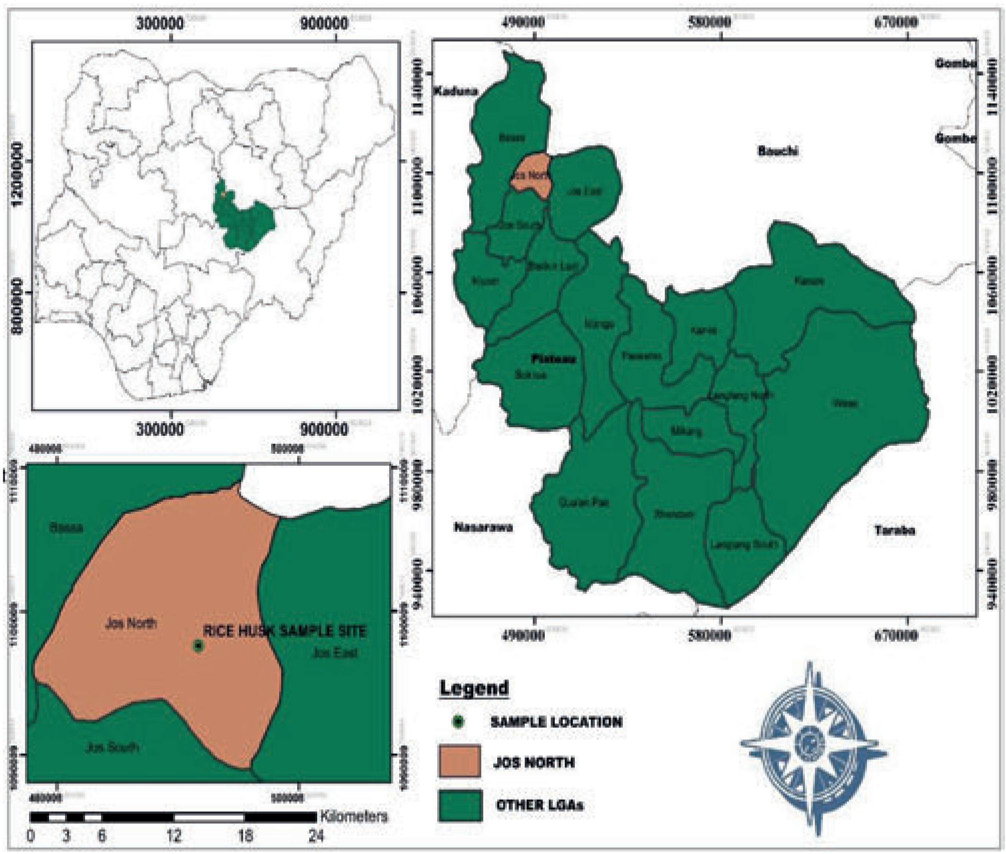

Fig. 2 Location map of Rice husk sample site
2. ábra A rizshéj mintavételi hely térképe

indicated that the ash from these agro-industrial waste materials has a high silica content, which qualifies them for use as pozzolanic materials. Additionally, it is environmentally friendly to use these agricultural wastes to get rid of a lot of waste that would otherwise contaminate the land, water, and air [14-16]. The aim of the study was to investigate the possibility of using rice husk ash geopolymer cement as an environmentally sustainable binder for adobe blocks instead of regular Portland cement.

2. Materials and research methods

2.1. Materials

Soil and rice husk are the materials used in this study. *Fig. 1* and *2* display the location maps of the sample acquisition. The material sample pictures are presented in *Fig. 3*.

2.1.1 Rice husk ash

The ash obtained from the process of burning rice husk is known as rice husk ash (RHA), and it was used in this study. The rice husk used for this study was sourced locally from Farin gada in Jos, Jos North Local Government Area, Plateau State, Nigeria, which is located between latitude 9.573206 90N and longitude 8.5203020E. The rice husk was burned, with the ash passing through B. S. sieve no. 200 with a 0.075 mm aperture was utilized to create the geopolymer cement in compliance with BS 1924 [17] to replace cement. *Table 1* displays the chemical makeup of the RHA that was utilized in the investigation. The material was slightly above the minimum requirement

Oxides	SiO_2	P_2O_5	SO_3	K_2O	CaO	LOI*	TiO_2	MnO	Fe_2O_3	Cr_2O_3	Al_2O_3
Composition (%)	74.20	3.60	0.91	4.68	3.74	15.3	0.64	0.43	6.42	0.22	0.65

**LOI = Loss on ignition*

Table 1 Chemical Composition of RHA
1. táblázat A RHA (rizshéjhamu) kémiai összetétele

Fig. 3 (A) Rice husk and rice husk ash (B) Casted earth block samples (C&D) Earth block samples during testing
3. ábra (A) Rizshéj és rizshéjhamu (B) Öntött földtégla minták (C&D) Földtégla minták vizsgálat közben

for pozzolans, as indicated by the chemical composition obtained for the RHA, which showed that the total percentage compositions of Fe_2O_3, SiO_2, and Al_2O_3 were found to be above 70% (for class C). But waste is harmful to the environment and needs to be disposed of properly, so the material was used to verify that it could be used to improve the properties of adobe blocks.

2.1.2 Soil

The study utilized clay soil from Naraguta Village in Jos North Local Government in Nigeria's Plateau State, which is located within Latitude 9. Latitude: 9882670 N, longitude: 8.8990750 E. In order to eliminate organic or biodegradable materials from the sample that could skew the results, the soil was collected at a depth of 0.5 meters.

2.1.3 Alkaline activators

The alkaline activators sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3) were combined with RHA to create geopolymer cement (GPC), which is the result of the reaction between an alkaline solution and alumina-silicate. The alkaline activators were mixed in the ratio 1:1, i.e 22% of each chemical (NaOH and $NaSi_2O_3$) with 56% of RHA by weight. RHA passing sieve No. 200 with aperture of 0.075mm was used in preparing the geopolymer cement mortar. The percentage replacement of ordinary Portland cement by geopolymer cement considered in this sturdy was 0%, 10%, 20%, 30%, 40%, 50%,60%, 70%, 80%, 90% and 100%. A maximum of 7% ordinary Portland cement was being replaced by the geopolymer cement.

2.2 Research methods

This experimental work presents the effects of using rice husk ash Geopolymer cement (RHA-GPC) as a substitute for cement in adobe blocks production. This work is based on the comparative study of mixing clay with ordinary Portland cement (OPC) and by partial replacement of the OPC with RHA-GPC. Additionally, 10 different replacement levels of RHA-GPC were taken into consideration, with the control sample being at 0%. The replacement levels of OPC were 0, 10, 20, 30, 40, 50, 60, 70, 80, 90, and 100%. Blocks measuring 150 mm by 100 mm by 100 mm were created by filling a greased metal mold with geopolymer mix mortar and vibrating it on a vibrating table (see *Fig. 3*). British Standard 1377 [18] for natural soil and British Standard 1924 [17] for modified soil samples were followed in the laboratory tests on soil to ascertain the particle size distribution and consistency limits of the soil.

Adobe block parameters such as the thermal conductivity, water absorption rate, ultrasonic pulse velocity (UPV), and compressive strength tests were performed on the moulded block samples. In order to ascertain whether there would be a difference in the rate of heat penetration through the modified blocks in comparison to the natural blocks, a thermal conductivity test was carried out in compliance with BS EN 12662. In order to ascertain how much water a block absorbs in a given amount of time, three block samples were used for each test. The blocks were submerged in water completely (according to the LNEC E 394:1993 standard) and partially (using the capillarity principle in accordance with the LNEC E 393:1993 standard), and weight measurements were taken every three minutes for a maximum of thirty minutes. The Ultrasonic Pulse Analyzer equipment, which measures the time in microseconds from the moment a wave leaves the transmitting transducer and reaches the receiving transducer, was used to conduct the ultrasonic pulse velocity (UPV) tests in accordance with IS: 13311(part 1)-1992. Direct, semi-direct, and indirect methods were used to perform the UPV test. After 7, 14, 21, and 28 days of curing, the compressive strength test was carried out independently using the destructive and non-destructive methods. The Rebound hammer BS 1881 (1983) was used for the non-destructive compressive strength test, while the Universal Testing Machine was used for the destructive compressive strength test. Scanning electron microscopy (SEM) and energy dispersive X-ray spectrometer (EDS) analyses were used to perform microstructural analysis on 28-day-cured samples of 100% soil-RHA-GPC mix and natural soil.

3. Results and discussion

3.1 Initial properties and soil classification

In terms of engineering characteristics, the natural soil was categorized as low plasticity clay CL soil in the USCS classification systems and as an AASHTO A-6 soil. With 35–22% of its finest particles smaller than the BS sieve 200, the unmodified soil has consistency limits of 60 percent (liquid limit), 46 percent (plastic limit), and 14 percent (plasticity index).

3.2 Sieve analysis

Since the soil is primarily of the silty clay variety, a sieve analysis test was used to ascertain the soil samples' particle size distributions. *Fig. 4* displays the findings from the sieve analysis test conducted at various levels of substitution for ordinary Portland cement (OPC) with rice husk ash geopolymer cement (RHA-GPC). The addition of RHA-GPC solidified the particles, which led to a persistent decrease in the fine content and an increase in the coarse content. This trend is in line with what has been found in related studies by Sadeeq et al. [19] and Salahudeen et al. [20].

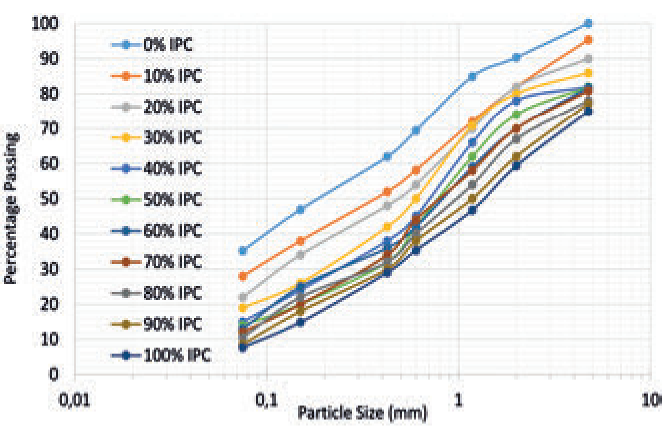

Fig. 4 Particle size distribution curves for different percentages of soil- RHA-GPC mix
4. ábra A talaj-RHA-GPC keverék különböző százalékos arányainak szemcseméret-eloszlási görbéi

3.3 Consistency limits

The boundaries where the plastic soils change from solid to semi-solid to plastic and to liquid depending on the moisture content at which the physical transformations take place are known as the Atterberg limits. *Fig. 5* displays the Atterberg limits results. Up to the maximum mix content of 100%, the consistency limits of the RHA-GPC modified soil steadily decreased at different percentage replacements (0 to 100%). The liquid limit decreased from a value of 60% for the natural soil to 25.2% after modification with 100% replacement of cement content with RHA-GPC. The plastic limit decreased from a value of 46% for the natural soil to 20% after modification with 100% replacement of cement content with RHA-GPC. The plasticity index decreased from a value of 14% for the natural soil to 5.2% after modification with 100% replacement of cement content with RHA-GPC. It was observed by Suhail *et al.* [21] and Salahudeen *et al.* [22] that the depressed double layer thickness of the soil is responsible for the decrease in Atterberg limits of soil when mixed with a stabilizing agent which results from bonding capability of the pozzolanic material and the cation exchange reaction by the detected cations as presented on *Table 1*.

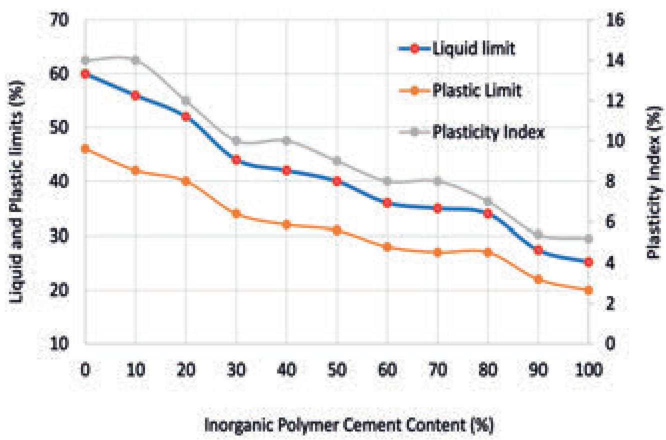

Fig. 5 Consistency limits results of soil with soil- RHA-GPC mix
5. ábra A talaj konzisztenciahatár-értékei a talaj-RHA-GPC keverékkel

3.4 Water absorption experimentation

Two methods were used in the water absorption test to find out how much water a block can absorb in a certain amount of time. In the first method, the blocks were completely submerged in a water bath; in the second, the blocks were partially submerged in the water bath to enable water absorption through the capillarity principle. The purpose of the test was to replicate real-world scenarios in which the blocks might be used in external walls that are exposed to floodwater absorption or rain. *Fig. 6* and *7* show the results of water absorption measured by weight every three minutes up to a maximum of thirty minutes, while *Fig. 8* and *9* show the results of weight gain as a percentage. After soaking in water for approximately six minutes, it was noted that the majority of the block samples became saturated. Additionally, it was found that as the RHA-GPC content rises, so does the blocks' capacity to absorb water. This could be because RHA has a high loss on ignition value (15.3 percent), which is characteristic of organic materials. Increased voids in the treated block samples relative to the untreated ones may be the cause of the increase in water absorption with an increase in RHA-GPC content [2, 23 and 24].

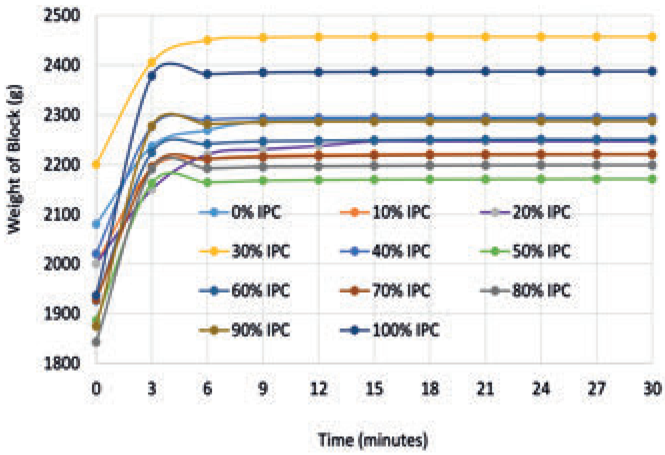

Fig. 6 *Results water absorption by weight for different percentages of soil- RHA-GPC mix (submerged)*
6. ábra *A vízfelvételi eredmények tömegszázalékban a talaj-RHA-GPC keverék különböző arányainál (merítéses vizsgálat)*

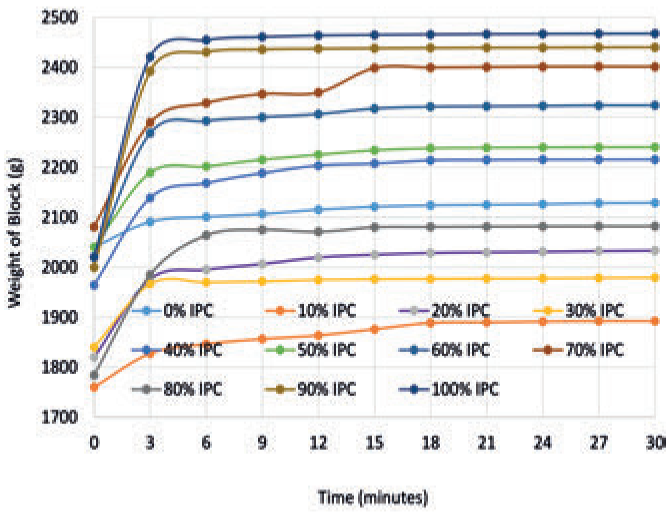

Fig. 7 *Results water absorption by weight for different percentages of soil- RHA-GPC mix (capillarity)*
7. ábra *A vízfelvételi eredmények tömegszázalékban a talaj-RHA-GPC keverék különböző arányainál (kapilláris felszívódás)*

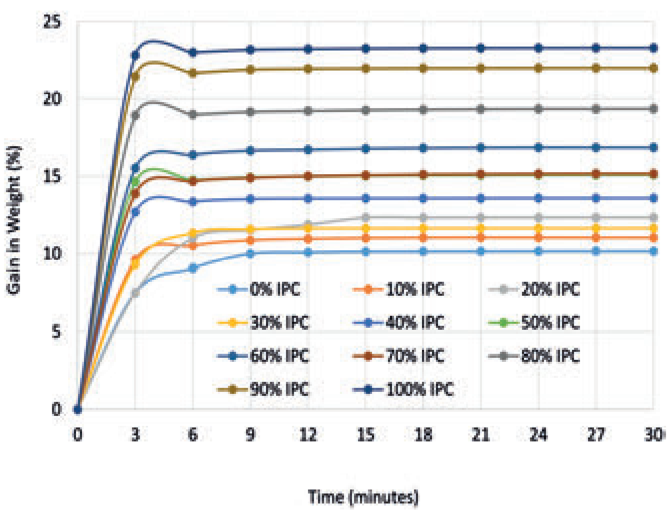

Fig. 8 *Results water absorption by percentage gain in weight for different percentages of soil- RHA-GPC mix (submerged)*
8. ábra *A vízfelvételi eredmények tömeggyarapodás százalékában a talaj-RHA-GPC keverék különböző arányainál (merítéses vizsgálat)*

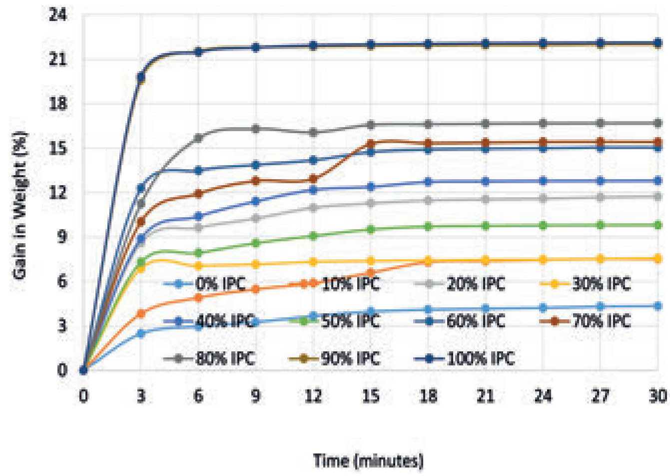

Fig. 9 *Results water absorption by percentage gain in weight for different percentages of soil- RHA-GPC mix (capillarity)*
9. ábra *A vízfelvételi eredmények tömeggyarapodás százalékában a talaj-RHA-GPC keverék különböző arányainál (kapilláris felszívódás)*

3.5 Ultrasonic pulse velocity test

The inner structure of the blocks was examined for the existence of any voids, cracks, or other openings using the ultrasonic pulse velocity (UPV) test. It is a technique for figuring out how tortuose building blocks are. It is interesting to note that tortuosity gauges how interconnected the voids are, whereas porosity gauges the quantity and presence of voids in a medium (block). *Fig. 10* displays the outcomes of the UPV tests using the Direct, Semi-Direct, and Indirect approaches. All three of the UPV's phases showed a decrease in pulse velocity, which is a sign that there are pores, voids, or cracks in the blocks. Vacuum created by voids will slow down the rate at which pulse waves pass through them, lowering the pulse velocity [2]. As shown by the results of the particle size distribution test, there may be a correlation between the increase in voids and larger particle sizes brought on by the solidification of the particles, which causes a continuous decrease in the fine content and an increase in the amount of coarse content. *Fig. 10* makes it clear that as the RHA-GPC content rises, the number and interconnectivity of the voids increase gradually.

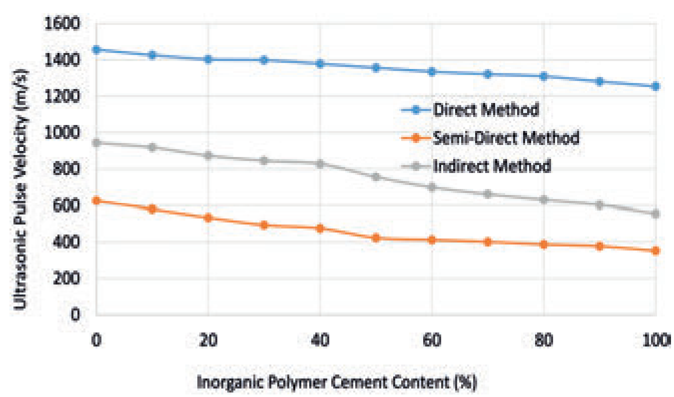

Fig. 10 *Ultrasonic pulse velocity results for different percentages of soil- RHA-GPC mix*
10. ábra *Az ultrahangos impulzussebesség eredményei a talaj-RHA-GPC keverék különböző arányainál*

3.6 Thermal conductivity test

The thermal conductivity test was conducted to determine possible variations in the heat penetration rate through the modified blocks compared with the natural block. The results of laboratory thermal conductivity test are presented in *Fig. 11*. A progressive decrease in the thermal conductivity was observed from a value of 1.26 W/Mk for the natural block to a value of 0.32 W/Mk when the block was modified with 100% cement replacement with RHA-GPC. This is an appreciable improvement in the thermal properties of the blocks. Thermal resistivity is a desirable property in building units like blocks most especially in the tropical region like Nigeria where the temperature can go as high as 42° centigrade. Increase in voids and tortuosity can be responsible for the decreased thermal conductivity as vacuum will decrease conductivity.

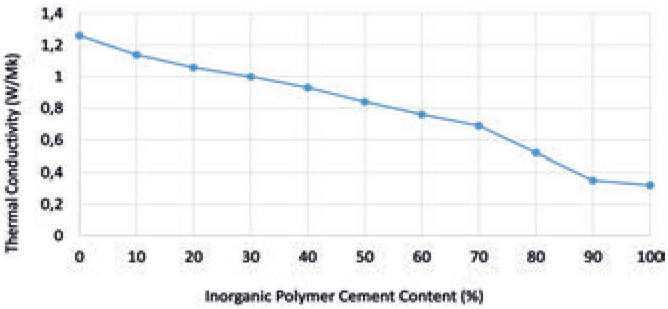

Fig.11 Laboratory thermal conductivity test results for different percentages of soil-RHA-GPC mix
11. ábra A talaj-RHA-GPC keverék különböző arányainak laboratóriumi hővezetési vizsgálati eredményei

3.7 Compressive strength test

Using both destructive and non-destructive methods, the compressive strength test was carried out after 7, 14, 21, and 28 days of curing. *Fig. 12* and *13*, respectively, show the compressive strength test results for the destructive and non-destructive approaches. It was found that as the RHA-GPC content increased, the compressive strength generally decreased. This trend is in line with earlier research by Salahudeen *et al.* [25] and Agbede and Joel [4]. The destructive test values are used to make recommendations in the majority of standards. Peak strength values of 4.5, 4.8, 5.2, and 6.9 N/mm² were noted for the untreated block samples using the destructive method for this study at 7, 14, 21, and 28 days of curing, respectively. The British Standard [26] recommended a minimum compressive strength value of 2.8 N/mm² for fired bricks. After 28 days of curing at 100% treatment, a compressive strength value of 2.8 N/mm² was noted. Several building authorities worldwide advised against using larger structural loads than 2 to 4 N/mm² [27]. All strength test results for this investigation met the minimum recommended value of 2.8 N/mm² at the 28-day curing period, up to the maximum RHA-GPC content of 100% (2.8 N/mm²). The formation of calcium aluminate and calcium silicate hydrates, which led to the bonding of the finer soil particles, is primarily responsible for the strength resulting from chemical reactions of this kind [2]. It is known that during the ion exchange process, the Ca^{2+} in the geopolymer reacted with the lower valence metallic ions in the soil structure, resulting in the agglomeration of the fine soil particles [28].

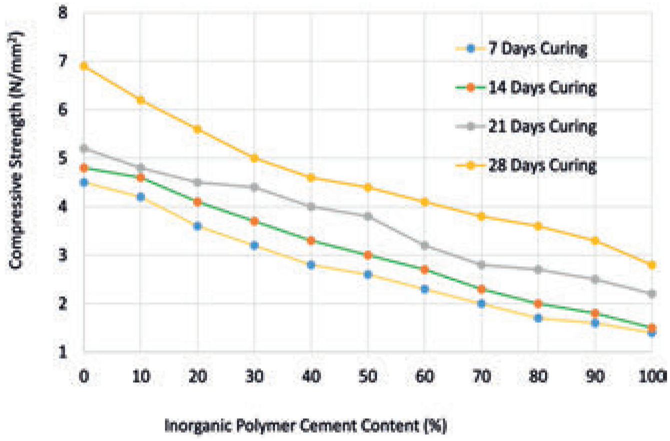

Fig. 12 Compressive strength test results for different percentages of soil- RHA-GPC mix (destructive test)
12. ábra Nyomószilárdsági vizsgálati eredmények a talaj-RHA-GPC keverék különböző arányainál (roncsolásos vizsgálat)

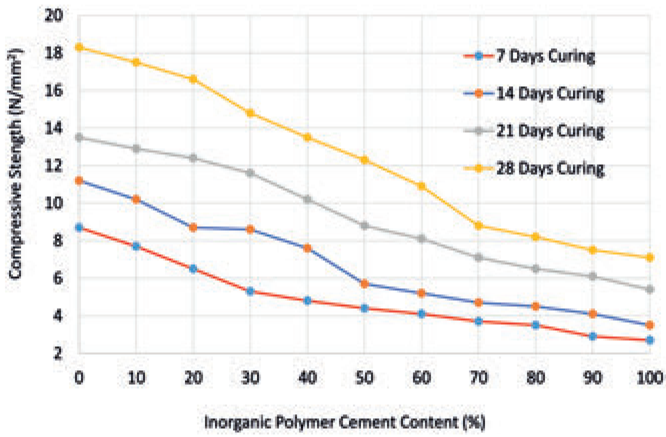

Fig. 13 Compressive strength test results for different percentages of soil- RHA-GPC mix (non-destructive test)
13. ábra Nyomószilárdsági vizsgálati eredmények a talaj-RHA-GPC keverék különböző arányainál (nem roncsolásos vizsgálat)

3.8 Microstructural analysis

The findings of analyses conducted using an energy dispersive X-ray spectrometer (EDS) and scanning electron microscopy (SEM) on 28-day-cured natural and 100% soil-RHA-GPC mix samples are displayed in *Fig. 14* and *15*, respectively. The composition of aluminosilicate minerals was noted in the elemental analyses of the natural sample using EDS. It is mostly composed of Si, Fe, K, Ca, Al, and Fe, with trace amounts of Mg and Ti. For the natural soil, the EDS found that 30% of the total oxide was present. After treating 100% of the RHA-GPC content, this value rose to 70%. Reyes *et al.* [29] observed that the carbon tape at the background of the sample holder attached to the machine is the cause of the elemental carbon found in the EDS. Comparing the aggregate particle sizes distributions of the natural block sample SEM to those of the RHA-GPC treated sample, it was evident that the former had smaller sizes. This might be the result of weakly bonded ions in the clay structure being replaced by the higher valent cation, Ca^{2+}, which is also more active in the mixtures [30 and 31].

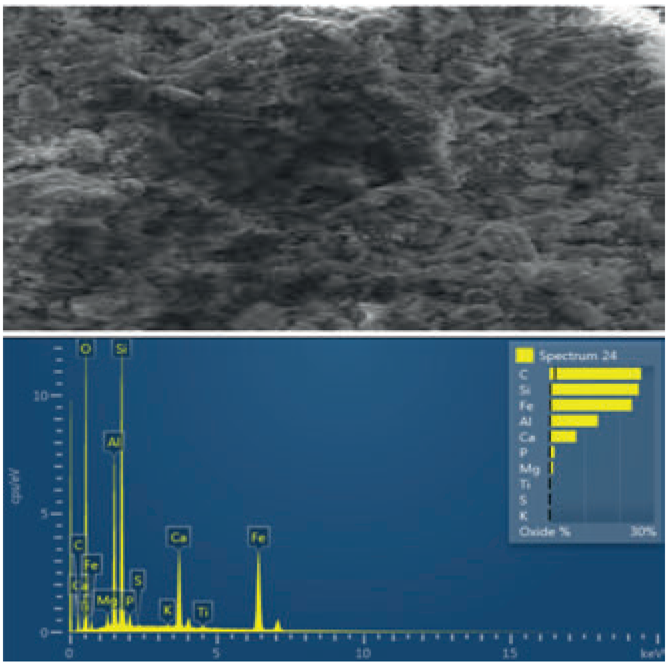

Fig. 14 SEM and EDS of natural sample
14. ábra A természetes minta SEM és EDS vizsgálata

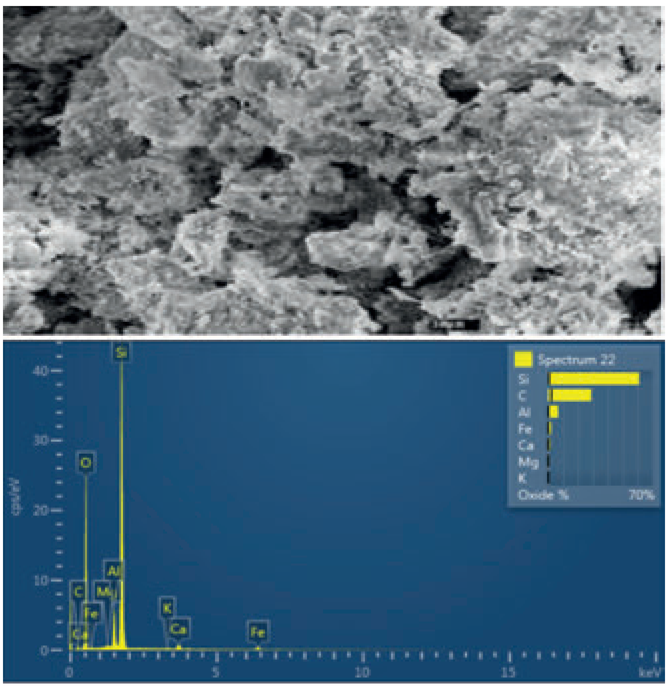

Fig. 15 SEM and EDS of 100% of soil- RHA-GPC mix
15. ábra A 100%-os talaj-RHA-GPC keverék SEM és EDS vizsgálata

4. Conclusions

The purpose of this study was to evaluate the viability of using rice husk ash geopolymer cement (RHA-GPC) in place of regular Portland cement when producing compressed earth blocks for affordable housing. The dimensions of the blocks used in this study are 150 x 100 x 100 mm. Blocks with varying percentages of the clay/RHA geopolymer mix (0, 10, 20, 30, 40, 50, 60, 70, 80, 90, and 100 percent) were produced. The modified blocks' engineering properties have significantly improved, according to the results. The fine particles solidified as a result of the RHA-GPC addition, gradually increasing the coarse content and decreasing the fine content. Additionally, it was found that as the RHA-GPC content rises, so does the blocks' capacity to absorb water. The presence of voids and/or cracks within the blocks is confirmed by the ultrasonic pulse velocity, which showed a decrease in pulse velocity. The results of the thermal conductivity test showed that the addition of RHA-GPC caused a vacuum, which in turn led to decreased conductivity, or increased resistivity. Even though the addition of RHA-GPC resulted in a decrease in compressive strength, the destructive method's minimum value after 28 days of curing was 2.8 N/mm^2 at 100% RHA-GPC content. The British Standard's minimum compressive strength value of 2.8 N/mm^2 for load-bearing fired clay blocks and precast concrete masonry units was satisfied by the lowest observed value. It is recommended that up to 100% RHA geopolymer content can be used to replace cement by weight in light of the compressive strength result of 2.8 N/mm^2 at 28 days curing period.

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