Assessment of Ihima Clay Admixed with Granite Dust and Rice Husk in the Development of Masonry-Fired Brick

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ORIGINAL RESEARCH

Abstract— Due to the high cost of conventional building materials, alternative and cheaper building materials are sought after for mass housing. Clay is a cheaper and highly available building material; hence, this study focused on the practicality of using Ihima clay in the production of fired masonry bricks. The clay was blended with rice husk and granite dust as additives in a proportion of 5 wt.% for rice husk and constant dosages for granite dust varying at 5, 10, 15, and 20 wt.%. The additives were introduced with the view of obtaining an insulation capacity. Firing was done at 5 ˚C/min until 850 ˚C was attained, after which samples were held for 2 hours in the furnace before being allowed to cool to room temperature. Developed samples were tested for firing shrinkage, porosity, water absorption and wear rate. The outcome showed that increasing the proportion of the granite dust from 5 to 20 wt.% resulted in a linear decline in firing shrinkage, porosity, water absorption, and wear rate.

Keywords— clay, granite dust, masonry brick, rice husk.

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1 INTRODUCTION

The demand for affordable housing is rising faster than its availability in almost every nation on earth. Nigeria's housing crisis is one of the issues facing developing countries (Basorun and Fadairo, 2012). From seven million units in 1991 to between twelve and fifteen million units in 2008, seventeen million units in 2012 (Adegboye, 2012), twenty million units in 2018 and twenty-two million units in 2019 (according to Alitheia, 2012), the national housing deficit has worsened. It will cost more than N50 trillion to address the housing shortage, according to Arigbigbola and Iranlowo's (2012) estimate that it costs N2.5 million to build a unit house (using sandcrete bricks). Sadly, there are indications that the gap will widen more.

The United States Census Bureau predicts that Nigeria's population will reach 264 million by 2050, compared to the United Nations' prediction of 289 million (Nkah, 2009). If this were the case, Nigeria would have the tenth-largest population in the world.

Rapid population growth raises the demand for housing as well as for the provision of essential utilities and services. The quality of the housing units that are accessible is also a concern in the majority of Nigerian cities, in addition to the quantity. As a result, there is an increase in household congestion, and as more Nigerians move from rural to urban regions, there are acute housing difficulties that need to be addressed.

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According to a study based on the salaries of public employees in Nigeria, it might take a public employee up to 25 years to build a home if he devotes 50% of his annual income to housing. There was an inbalance between housing supply and demand despite the effort of government to address this (Nkah, 2009). The demand for bricks will continue to rise along with the annual increase in brick production worldwide (Zhang, 2013).

One of the main causes of Nigeria's ongoing housing shortage is the high price of ordinary Portland cement (OPC), a necessary ingredient in concrete. Since cement, a key component of concrete and sandcrete, is becoming more expensive, it is imperative to investigate possible substitutes or supplements to lower the cost of home construction. The world's nonrenewable limestone supply has been depleted by the production of cement, which also consumes a lot of energy. River sand has also been one of the most popular additives for the fine aggregates in concrete, but due to abuse, river sand resources have been depleted, increasing material costs. Finding less expensive and more environmentally friendly alternatives to cement and river sand is thus important.

Due to its low price and superior thermal insulation, clay-fired brick is a practical substitute for concrete brick, claims Folaranmi (2009). One of the minerals that is most prevalent on earth is clay. Bricks that have been fired are made by forming clay into uniformly sized rectangular blocks, and then drying and burning those blocks (Younossa et al., 2016). The bricks can be efficiently piled and do not need more powerful lifting equipment because of their modest weight. Clay brick installation also doesn't cost much because it's a straightforward method. The first artificial building material created by humans was clay brick. Compared to stone and concrete bricks, they are more fire-resistant. Compared to other building materials, clay bricks provide a more physically comfortable living environment (Younossa et al., 2016).

Construction of "cooler" homes has become necessary as a result of the altered environmental conditions brought on by climatic change, especially in tropical nations. Numerous studies have been conducted to create low-cost, thermally insulating, and lightweight construction bricks in response to this demand.

The creation of burnt clay bricks using waste materials has drawn a lot of academic attention throughout the years. Clay material's ability to make bricks generally improves when trash is added. This garbage will remain in the environment for decades if it is not recycled into useful goods (Chandana et al., 2012). Waste materials like rubber, limestone dust, rice husk, wood sawdust, fly ash, cow bone powder ash, and cow manure have all been tried to be included to burned clay bricks (Danupon et al., 2008).

Pores are produced when lighter additions, such as rice husk (RH), are consumed during the firing process. This makes it possible to alter the bulk density of the bricks and helps create lighter, porous bricks with superior thermal insulation properties. Additionally, as the rice husk burns away, heat penetrates the inside core of the bricks, preventing an unburned core, and leading to more evenly burned bricks. This acts as extra fuel, reducing the overall amount of fuel used during a fire.

In most situations, adding light wastes to clay bricks, such as rice husk, enhances their insulating properties, but a decrease in strength performance is also observed. According to research by Velasco et al. (2014), adding waste materials like rice husk and wood sawdust to baked bricks might increase their shrinkage, porosity, and insulating properties while degrading their strength. In his study of the properties of clay bricks mixed with waste glass fragments, he concluded that compressive strength increased as waste glass and firing temperature grew. In addition, Ngayakamo et al. 2021 found that adding granite dust waste to burnt bricks increased the compressive strength of the bricks. It shows how the inclusion of granite dust waste increased the strength of burnt bricks. Manjunath et al. 2021 demonstrated the effect of granite dust on strength improvement, therefore, granite dust waste can be employed as a strength-impacting agent in the bricks to address the problems of decreased strength in burnt clay bricks caused by the use of rice husk. As a result, the goal of this research was to create burnt bricks using rice husk and granite dust waste in addition to Ihima clay. It was assessed how the mixture will affect the physical, mechanical, and thermal qualities.

2 MATERIALS AND METHODS
2.1 MATERIALS
The materials used in the research are clay, rice husk, granite dust and water.
2.2 MATERIALS PREPARATION
The clay utilized in this study was excavated from a clay hill in the Ihima village (the latitude and longitude of Ihima clay deposits was approximately 7.43333°N and 6.116667°E), Okehi Local Government Area, Kogi state, Nigeria. The rice husk was gathered from a local merchant in the same Local Government, while, granite

dust was procured from a nearby quarry in the city.
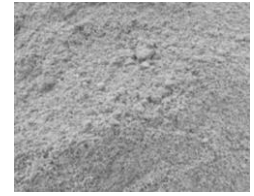

Plate 1: Sundried rice husk   Plate 2: Sieved granite dust

The bulk clay was broken into smaller pieces, transferred into a bucket and water was poured into the bucket until the bucket was full. The mixture was left for 24 hours after which the water was poured off to remove water-soluble impurities. The procedure was repeated one more time and the left-over clay was spread in open air for 120 hours. Afterwards, the powder was oven dried at 110oC for 12 hours to remove remaining moisture before being milled and sieved to 300 microns passing using a Ball Mill: Mixer Mill MM 500 control and Sieve shaker: AS 200 control. Sieved clay was collected for sample processing. Collected granite dust was treated in a way like clay and sieved to 150 microns passing. was also pulverized using a ball mill and sieved to a particle size of 150 μm. The procured rice husk was soaked in water for 24 hours and spread in an open atmosphere for 120 hours after which the dried rice husk was sieved to 150 μm passing and collected for sample preparation.
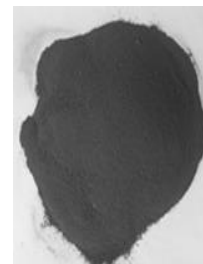

Plate 3: Clay sundried in the open   Plate 4: Sieved clay   Plate 5: Weighing of clay

2.2.2 SAMPLE PREPARATION
The acquired sieved clay was transferred into a mixer (Mixer Mill 500), which was then worked for 5 minutes to ensure adequate mixing, after which water was added at the water-clay ratio of 0.3 and the mixer was driven for another 5 minutes to obtain highly viscous clay slurry. This was extruded into a 170 x 90 x 75 mm mould and compressed at 10 MPa to produce a set of control samples. The subsequent set of samples was produced by combining clay, rice husk and granite dust in a mixer (in varying proportions as shown in Table 1), adding water (at 0.3 water-clay ratio), then extruding the mixture into the same mould, and compressing it at 10 MPa. Before being placed in the oven, the samples were kept undisturbed in the open air for 12 hours to enable the mixture to settle and acquire a measure of dryness, compactness, and stability. The samples were oven-dried for eight hours at 110 ˚C to remove moisture. Samples

were heated in an electric furnace at a rate of 5 ˚C/min until 850 ˚C was reached and then soaked for two hours. Before testing, the samples were allowed to cool in the furnace (to reduce thermal shock when immediately exposed to the environment at ambient temperature). The proportions of the blend are presented in Table 1.

Table 1. Mix proportion of samples produced.

Granite dust (wt. %)	Rice husk (wt.%)	Clay (wt.%)
0	3	97
5	3	92
10	3	87
15	3	82
20	3	77

2.2.3 PROPERTY EVALUATION

Brick samples were prepared for each sample group listed in Table 1 and tested for firing shrinkage, apparent porosity, water absorption, and wear rate as part of the property evaluation.

2.2.4 PRELIMINARY TEST ON MATERIALS

a) Physical test

At a room temperature of 29 degrees Celsius, tests were performed on clay, granite dust, and rice husk. The specific gravity of materials was estimated by IS 2720 Part 111 (1964) and ASTM C127 (2001) by using the following relationship:

$$\text{Specific gravity} = \frac{M_2 - M_1}{(M_4 - M_1) - (M_3 - M_2)} \qquad (1)$$

M_1 is the mass of the bottle when empty
M_2 is the mass of the bottle with a sample
M_3 is the mass of the bottle and sample when filled with water
M_4 is the mass of the bottle when full of water
The bulk density of each material was calculated as stated in BS 812-2 (1995) specification using the relation;

$$\text{Bulk density} \quad \frac{M_1}{M_2 - M_3} \qquad (2)$$

M_1 is the mass of the dried sample
M_2 is the mass of dried sample suspended in water
M_3 is the mass of the saturated sample when suspended in the air
Atterberg limit test was conducted on the clay in line with ASTM D4318-17e1 (2017) and soil classified as stated in BS 1377: Part 2(1990).

b) Chemical Analysis of Materials

X-ray Fluorescence analysis was performed to determine the percentage weight of the oxide content of the materials (clay, granite dust, and rice husk) employed in this study.

2.2.5 PHYSICAL PROPERTIES OF BRICKS

Among these characteristics are firing shrinkage, apparent porosity, water absorption, and saturation coefficient.

a) Firing Shrinkage

The initial length of the samples after manufacture (in green state), length after oven drying, and length after fire were measured following ASTM C326 to determine the firing shrinkage (reported as a percentage) (ASTM C326-09, 2014).

$$\text{Firing Shrinkage (\%) is given as} \quad \frac{L_2 - L_3}{L_2} \times 100 \qquad (3)$$

L_3 is the length of the sample after firing
L_2 is the length of the sample after oven drying.

b) Apparent Porosity

The apparent porosity was determined using the ASTM C373 (ASTM C373-88, 2006) method. The samples of bricks were dried in an oven at 110 degrees Celsius for six hours while their dry weight in the air was recorded. The sample was submerged in water for twenty-four hours before being wiped clean and weighed. The weight of the sample while it was suspended in air and water was determined and recorded. As a percentage, apparent porosity is given as the ratio of change in mass to external volume. Volume exterior is computed as the difference between mass suspended in water and mass saturated when submerged in water for 24 hours, per ASTM C373 (2006).

$$\text{Apparent porosity (\%) is given as} \quad \frac{M_s - M_d}{M_s - M_w} \qquad (4)$$

M_s is the saturated mass of the sample in the air
M_d is the mass of dried sample in the air
M_w is the mass of the saturated sample when suspended in water

c) Water absorption

The samples were dried in an oven at 110 degrees Celsius for three hours to ensure surface dryness, then cooled to room temperature and weighed. The samples were then totally submerged in water at room temperature (29 degrees Celsius) for 24 hours. Each sample was removed, cleaned with a fresh towel, and reweighed.

This test was conducted following ASTM standard procedure (ASTM C373-88, 2006). Using equation 2.5, samples submerged in water for 24 hours at room temperature (29 ᵒC) were tested for water absorption. To conduct the 5 hours water absorption test, samples were submerged in boiling water for 5 hours. Due to porosity produced during the fire, the sample absorbed water when submerged in a body of water, as shown by the existence of bubbles during immersion. Using the equation, water absorption was calculated.

Water absorption (%) (24 hours immersion)
$$\frac{M_s - M_f}{M_f} \times 100 \qquad (5)$$

M_s is the saturated mass of the sample in the air (24 hours immersion in water)
M_f is the mass of the fired sample in the air
Also for 5 hours of boiling,
Water absorption (%) (5 hours boiling)
$$\frac{M_{sb} - M_f}{M_f} \times 100 \qquad (6)$$

M_{sb} is the mass of the sample in the air (after 5 hours of boiling)
M_f is the mass of the fired sample in the air.

d) Saturation Coefficient

It is a crucial criterion for measuring the durability of bricks. The saturation coefficient is computed as the ratio of water absorption after 24 hours of immersion to that after 5 hours of boiling (ASTM C373).

$$\text{Saturation Coefficient} \quad \frac{WA}{WB} \qquad (7)$$

Where:

WA is the water absorption value at 24 hours of immersion in water

WB is the water absorption value at 5 hours of boiling in water

2.2.6 MORPHOLOGY EXAMINATION

The morphology of the samples was investigated using a scanning electron microscope (JOEL JSM-7500F).

3.0 RESULTS AND DISCUSSION

3.1 RESULTS

Samples used for all tests were manufactured following the standards (American Standard for Testing and Materials (ASTM), British Standard Group (BS), and Bureau of Indian Standards (IS)) of quality fired brick for masonry use, in terms of shape, size, colour, appearance, cracks, and the material used to manufacture the bricks. The results acquired from the test analysis were compared to the current standard values for credibility.

3.1.1 PHYSICAL PROPERTIES

Clay, granite dust, and rice husk had specific gravities of 2.75, 2.44, and 0.64, respectively, whereas their bulk densities were 1.62, 1.55, and 0.16 g/cm^3, respectively. As a consequence, the clay is heavier than granite dust and the rice husk. The Atterberg limits investigation for the utilized clay yielded values of 42.1% for liquid limit, 24.4% for plastic limit, and 17.7% for plasticity index. Going by BS 5930 (2015) classification of clay, Ihima clay is classed as medium plastic clay. Also, comparing the data with Raj's (2012) guidelines (for soil used for masonry), Ihima clay has a high degree of flexibility and particle cohesiveness. The plasticity index falls within the permitted range of 10 to 20% for soils used for masonry (BS 1377-7, 1990), and the shrinkage limit of 10.4% indicates the maximum shrinkage predicted for fired bricks. A porosity of 41.4% reveals a significant number of pores in the clay sample. The soil's consistency index was determined to be 0.45, suggesting that it is between its liquid and plastic limits, indicating a measure of good stability. The difference between the liquid limit and the soil's moisture content (2.2%) was 12.9%, which offered an estimate of the water percentage employed in the mixing, which was chosen not to be greater than 12%.

3.1.2 CHEMICAL ANALYSIS

The chemical composition of the clay reveals that it contains 64.5 % silica (SiO_2), which satisfies the compositional criterion for manufacturing burnt clay bricks following BS 1377-3 (2018) standard. Granite dust reveals a higher content of silica, a needed chemical compound for flux during firing. Also, the rice husk is reported to majorly contain silica. Another elements inherent in large quantities is alumina though insignificant in the case of rice husk. The silica and alumina contents in clay meant for masonry have been recommended to be between 50 – 60 % silica and 10 – 20 % alumina.

Table 2 Elemental Compositions of Materials Used

Compound	Ihima Clay (%)	Granite dust (%)	Rice husk (%)
SiO_2	64.50	69.44	69.20
Al_2O_3	19.30	13.15	2.11
Fe_2O_3	4.79	2.10	2.25
MgO	0.64	0.34	0.88
CaO	1.44	2.01	3.94
K_2O	0.30	4.90	5.84
Na_2O	0.26	2.90	0.38
MnO	0.10	0.02	0.20
CuO	0.07	0.00	0.11
Other Oxides	5.39	3.14	3.33
*LOI	3.21	2.00	11.76

*LOI is a loss on Ignition

3.1.3 FIRING SHRINKAGE

Important in determining the degree of densification during burning is shrinkage. The firing of clay bricks results in the loss of volatile components and the evaporation of water previously contained in the bricks. At a high temperature, clay particles compress together, so decreasing the pores between particles and minimizing voids, thereby increasing the cohesiveness of the bricks. Nonetheless, a fast temperature rise might cause abrupt shrinkage, which can result in fractures and dimensional flaws.

As shown in Figure 1, increasing the dosage of granite dust results in a decrease in firing shrinkage. Linear shrinkage of the control sample is 4.8 ± 0.4% which demonstrates the biggest percentage change in dimension, indicating a substantial quantity of volatile material was evolved during firing. In addition, the spacing between the clay particles was high; nevertheless, this gap shrunk during burning, resulting in a significant amount of brick shrinkage. Inclusion of granite dust at 5, 10, 15, and 20 wt.% resulted in 29.5, 41.4, 57.0, and 67.3% decreases in firing shrinkage. The reduction is based on the infilling of pores by the dust particles lowering porosity, and consequently reducing firing shrinkage.
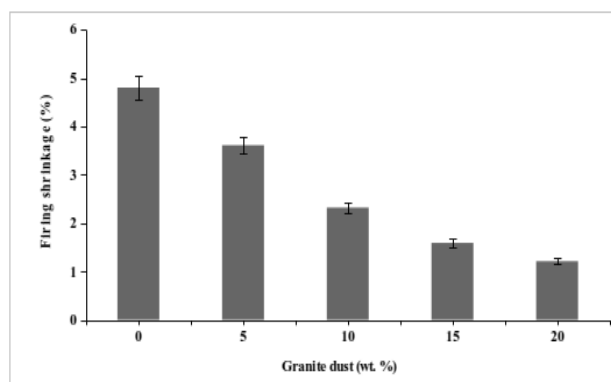

Figure 1: Effect of granite dust on firing shrinkage

In summary, it is observed that granite dust addition between 5 – 20% resulted in a linear decrease in firing shrinkage, hence improving the dimensional stability of the material (Weng, Lin and Chiang 2003). Going by ASTM C 71 recommendation of 8% maximum shrinkage in fired bricks, all samples satisfied the requirement.
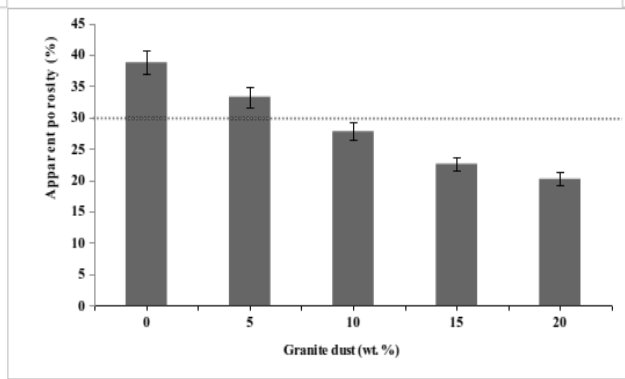
Plate 6: Fire Bricks

Figure 2: Effect of granite dust on apparent porosity

3.1.4 POROSITY

Apparent porosity is the proportion of a material's mass that consists of pores. Bricks' porosity influences their bulk density, mechanical characteristics, and performance. These pores serve as points of water entrance into the bricks and severely impact their service-life durability. In addition, the pores serve as a location for the aggregation of salt in bricks, which has a detrimental effect on the quality of the bricks.

Figure 2 demonstrates that as the proportion of granite dust increased from 5 – 20 wt.%, porosity decreased, suggesting that the volume of pores decreased as the percentage of granite dust appreciated. The waste granite particles bonded with clay bodies, therefore contributing to the bricks' densification. The porosity of the control sample is 38.8% and with the addition of 5, 10, 15, and 20 %, there was a significant 14.2, 28.8, 41.8, and 47.9% reduction in porosity. The result is consistence with the outcome of Phonphuak et al. (2016) as the progressive inclusion of glass powder triggered a linear reduction in porosity. BS 3921 (1985) prescribed a porosity of ≤ 30 % for masonry, which means that 10, 15, and 20 % granite dust addition produced brick samples that met the requirement.
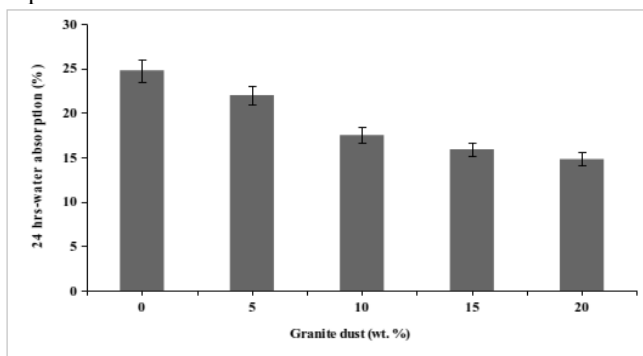

Figure 3: Effect of granite dust on 24-hrs water absorption of fired bricks

3.1.5 WATER ABSORPTION AND SATURATION

COEFFICIENT

Due to the existence of pores, water is absorbed by bricks, demonstrating that water absorption is directly related to porosity. In accordance with ASTM C62 (ASTM C62-04, 2004), 24 hours of immersion in water and 5 hours of boiling were tested for water absorption, and the results are shown in Figures 3 and 4.

Figure 3 displays the value of water absorption for samples immersed in water for 24 hours. It was noticed that as the percentage of granite powder increased in the fired bricks, water absorption decreased linearly owing to the reduction of porosity as well as the increasing densification and compaction of the particles after firing. As per ASTM C 62 prescription of ≤ 20 % for 24hrs-water absorption, samples prepared with 10, 15, and 20 % satisfied the prescription.
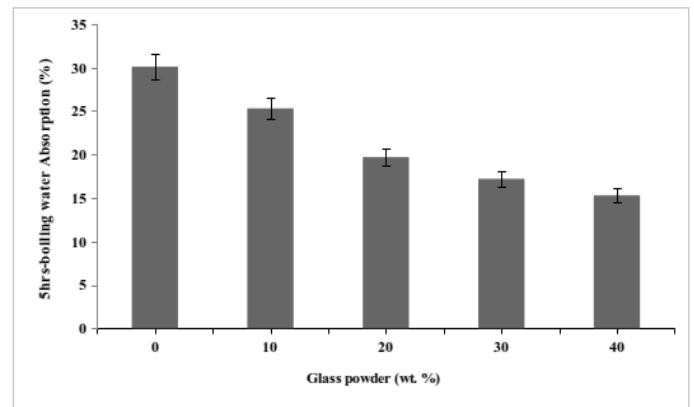

Figure 4: Effect of granite dust on 5-hrs boiling water absorption of fired bricks

As the quantity of granite dust appreciated in the bricks, water absorption decreased linearly from 30.1 % for the control sample to 15.3 % at 40 wt. % granite dust inclusion (Figure 4). The reason for the linear decline is associated with a linear decrease in porosity as mentioned under 24-hrs water absorption. According to ASTM C67/67M-19 (2019) standard, 5hrs-boiling water absorption of ≤ 25% is acceptable for fired bricks, in which case, samples prepared with 5, 10, 15, and 20 % granite dust satisfied the requirement.
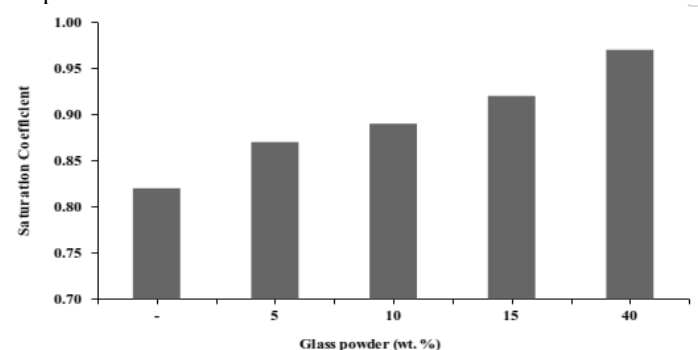

Figure 5: Effect of granite dust on saturation coefficient of fired bricks

As seen in Figure 5 the saturation coefficient has a value between 0.82 and 0.97. Bricks prepared with 0, 5, and 10% granite powder complied with the ASTM C67 (2003) standard, which specifies a maximum coefficient of 0.9 for load-bearing burned bricks used in typical weather conditions.
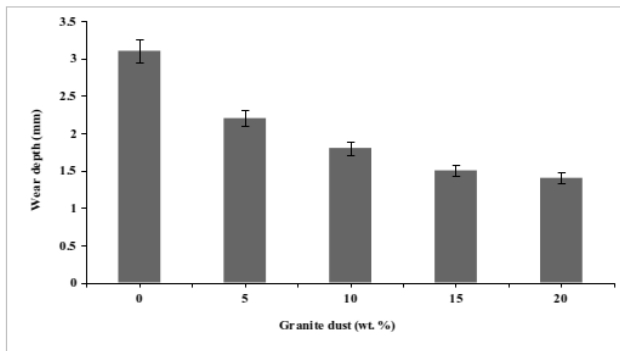
3.1.6 WEAR RATE

Figure 6: Effect of granite dust on wear rate of fired bricks

The variation in wear depth for each sample is shown in Figure 6. The wear rate significantly decreased as the samples' granite dust content increased. A decreased wear rate indicates an increase in the bricks' wear resistance. The addition of granite dust increased the cohesiveness of the particles, which in turn increased the samples' hardness and wear resistance. The peak wear resistance is indicated in a sample containing 20% granite powder, whereas the lowest wear resistance is found in the control sample at 0% granite powder proportion. The wear depth of masonry bricks was limited by TS 2824 to no more than 3 mm, hence, glass powder addition of 5 – 20% yielded brick samples that satisfied the requirement.

3.1.7 MICROSTRUCTURAL AND ELEMENTAL ANALYSIS

Figure 7 presents the microstructural images of the fired bricks. As observed in Figure 7a for the control, the surface is observed to contain major pores corroborating the high porosity recorded against 0% granite dust. With increasing granite particles, the pores are observed to reduce at 5, 10, 15, and 20 wt.% as observed in Figures 3.7b, c, d, and e. The images in Figure 7b – e justify the lower water absorption and improvement in thermal conductivity. It is also observed from the figures, the existence of coherent phases contributed to the enhancement of compressive and flexural strengths
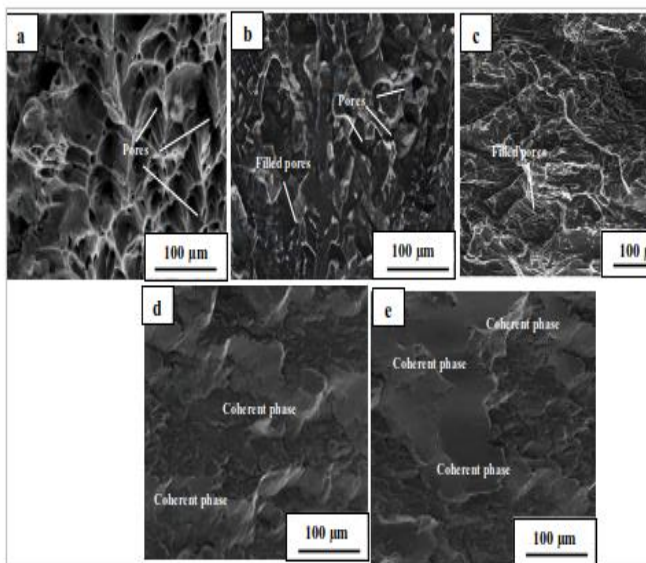

Figure 7: Effect of granite dust on wear rate of fired bricks at (a) 0 wt.% (b) 5 wt.% (c) 10 wt.% (d) 15 wt.% (e) 20 wt.%

4.0 CONCLUSIONS

Based on the experimental data gathered from the study, observations, and analysis of the features of burned clay bricks with rice husk at 3 % and granite dust (5, 10, 15, and 20 wt. %), the following findings are drawn:

1) According to Sanjay et al. (2013), Rajput (2006), and BS 1377-7 (1990), BS 1377-3, the physical and chemical analysis of Ihima clay revealed that it satisfied the specifications for clay used in burned masonry bricks.

2) As the percentage of granite dust in the samples increased, dimensional stability, densification, and compactness improved, resulting in a decrease in shrinkage, porosity, water absorption, and wear, while compressive and flexural strength and thermal conductivity were improved from 0 to 20 % glass powder inclusion.

3) 5, and 10 wt. % showed a reduction in bulk density relative to the control bricks, while 15, and 20 % depicted an increase in bulk density.

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