



Effects of Agricultural waste ash additives on Lankavri and Kpantinapu clays for Possible Industrial Applications



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ABSTRACT

The effects of agricultural waste ash additives on Lankavri and Kpantinapu clays for possible industrial applications were investigated. Virgin clays were excavated as mined from Lankavri Town in Yorro Local Government Area and Kpantinapu Town in Jalingo Local Government Area both in Taraba State, Nigeria and processed to about 98 % purity using standard laboratory procedures. The coconut shells (CS), cow bones (CB) and rice husks (RH) were sourced locally within the Jalingo metropolis and calcined into amorphous ash by pyrolytic decomposition. The clays were blended at a 50: 50 weights % ratio and the ashes were each separately mixed and compounded with the clay blend at 90: 10, 80:20 and 70:30 weight percentage ratios. These compounded samples were then subjected to firing at different temperatures of 900°C, 1000°C, 1100°C and 1200°C and subsequently characterised for linear shrinkage, bulk density, apparent porosity and water absorption coefficient. Six selected admixtures of 10 % CS, 10 % CB, 10 % RH, 20 % CS, 20 % CB and 20 % RH together with the blended control of Lankavri and Kpantinapu were subjected to SEM analysis. The results obtained showed that the agricultural waste ashes did not significantly affect the physicochemical properties of the blended Lankavri and Kpantinapu clays much. However, the 10 % admixture of each ash presented values very close to those of the control, with the 10 % CS showing the best results. It is therefore concluded that for purposes of recycling for environmental safety and control, not more than 10 % CS should be added to a blend of Lankavri and Kpantinapu clays when deployed for industrial use for refractory production.

Keywords:

Agricultural waste ash,
Additives,
Lankavri,
Kpantinapu clays

INTRODUCTION

The urgent need to develop the foundry industry to meet the technological needs of the country has generated great interest in the characterization of locally available materials (Aigbodon *et al.*, 2009). Environmentally friendly, energy-saving recycling properties of material production have been among the very important research focuses for decades. Owing to environmental regulations, the demand for high-insulation bricks is increasing (Bergaya *et al.*, 2006; Bhoj *et al.*, 2023; Hossain *et al.*, 2019).

Clay is a widespread and abundant mineral resource of great industrial importance for an enormous variety of uses (Murray, 2007; Odeyemi *et al.*, 2024; Moore, 1996; Mukherjee, 2013; Klein, 2002; Millot, 1970). Recently, using ash from agricultural waste as additives such as maize fibre, palm kernel, cow bone ash, coconut fibre, and others has become more important in material science, especially as a sustainable option for different industrial uses (Sadik *et al.*, 2014; Karhu *et al.*, 2019; Irani *et al.*, 2020; Sagar *et al.*, 2023; Sani and Nzihou, 2017; Sultan *et al.*, 2024; Wafaa *et al.*, 2024; Hasan *et al.*, 2023).

Agricultural waste, which comes from crop processing and production, is often thrown away or not managed well, leading to environmental issues. Yet, the ash from burning these wastes can be a useful pozzolanic material, improving the properties of clays like Lankavri and Kpantinapu. Adding agricultural waste ash helps lower the environmental effects of agricultural byproducts and enhances the mechanical and thermal qualities of clay materials. This combined benefit supports the creation of eco-friendly composites for use in construction, ceramics, and other fields,

showing a move toward more sustainable methods and encouraging a circular economy (Hossain and Roy, 2019; Hossein *et al.*, 2019; Hu *et al.*, 2020; Dextral, 2002; M'barek *et al.*, 2015; Zharmenov *et al.*, 2022). Therefore, it is important to understand the advantages of these additives for improving industrial uses. The rate of development and application of such new materials and the constant demand for quality building and household materials necessitated the need for this study.

Rice husk ash is a biomass additive product found in large quantities in Jalingo Metroplis, Jalingo Local Government Area, Taraba State, Nigeria. Additives are non-metallic materials that possess chemical and physical properties applicable to structures, which are readily available, environmentally-friendly and inexpensive (Murray, 2007; Amran *et al.*, 2021; Zhang *et al.*, 2010; Velde, 1980). The use of biomass additives improves some physical and mechanical properties of clay. Biomass additives are used in clay to change its properties and either accelerate or retard setting hardening, segregation, hardness, workability, strength, ductility, and other mechanical properties.

The study of altered clays, especially with the addition of agricultural waste ash, shows good potential for many industrial uses. Lankavri and Kpantinapuclays can be improved to better their physicochemical traits, which expands their use beyond regular functions. For example, using sustainable resources such as agricultural waste ash can enhance the flow properties of clays, making them fit for membrane technologies that help with water shortage problems (Al-Shaeli *et al.*, 2022). Moreover, the ability of altered clays to stabilize soil can be used in building and infrastructure work, helping to improve subgrade materials and boost overall strength (Bhardwaj *et al.*, 2017). Therefore, the combination of clay alteration and agricultural waste use presents a positive path for promoting eco-friendly industrial practices while also improving material effectiveness in various uses. The present work is an attempt to investigate the effects of agricultural waste ash additives on Lankavri and Kpantinapuclays for possible industrial applications

MATERIALS AND METHODS

Materials

The materials that used for this study include the following: weighing balance/ spring balance, measuring cylinder, buckets (basin), scrapper/hand trawler, presser, lubricant/separator (engine oil), mould (wooden), brush, ruler drier, sieve, mortar, and pestle, and head pan.

Sample Preparation

The clays used for this research were obtained from two different locations, reasonably separated from one another namely at the deposits in Lankavri and Kpantinapu communities in Taraba State of Nigeria. Agricultural wastes namely rice husks; coconut shells and cow bones were collected from Kona and Jalingo markets both in Jalingo Local Government Area in Taraba State. The rice husks and coconut shells were dried in air, grounded into powder using a grinding machine, while the cow bones were sun-dried, burnt, crushed and sieved, after which the ash was collected. The powders and the cow bone ash were well grounded, sieved and stored for the formation of clay-powder/ash composite bodies. The crushed Lankavriclay, Kpantinapu clay, coconut shell, cow bone and rice husk ash are presented in Figure 1a-e.

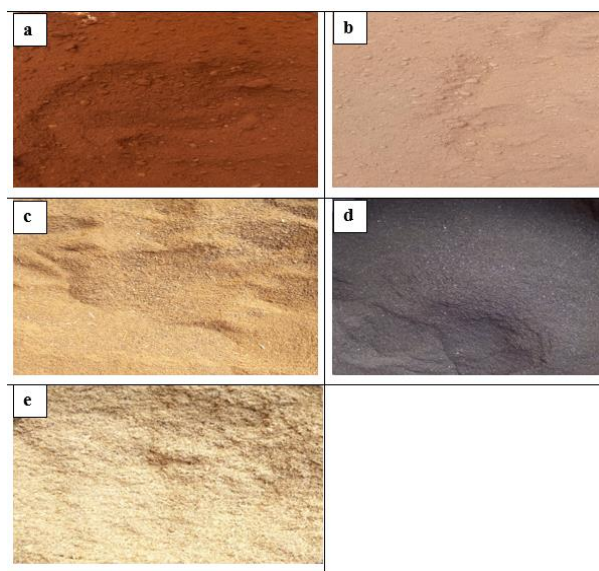


Figure. Samples of crushed: (a) Lankavri clay, (b) Kpantinapu clay, (c) Coconut shell, (d) cow bone ash and (e) rice husk.

Subsequently, the clay samples were mixed to varying proportions of 90:10, 80:20, 70:30, 60:40, 50:50, 40:60, 30:70, 20:80, 10: 90 for Lankavri: Kpantinapu clays respectively.

The clay samples were shaped into rectangular blocks with dimensions of 9 cm by 5.5 cm by 3.5 cm. These blocks were carefully moulded to ensure uniformity in shape and size. The initial length, width, and height of each sample were measured using a calliper to the nearest millimetre. The clay samples were then dried in an oven

at 105°C for 24 hours to ensure complete moisture removal. After drying, the samples were fired in a furnace at temperatures of 900°C, 1000°C, 1100°C, and 1200°C, with each temperature being maintained for 2 hours. The final dimensions of the clay blocks were measured again after firing.

Linear Shrinkage

The linear shrinkage was calculated by measuring the change in length, width, and height before and after firing using the formula:

$$\text{Linear Shrinkage (\%)} = \frac{L_o - L_f}{L_o} \times 100 \quad (1)$$

Where L_o is the initial measurement and L_f is the final measurement after firing.

Bulk Density

The fired clay samples were weighed using an electronic balance to determine their mass. The volume of each sample was measured using the water displacement method, where the sample was immersed in water, and the volume displaced was recorded. Bulk density was calculated using the formula:

$$\text{Bulk density (g/cm}^3\text{)} = \frac{\text{Mass of sample (g)}}{\text{Volume of sample (cm}^3\text{)}} \quad (2)$$

Water Absorption

The fired clay samples were first weighed in their dry state. The samples were then immersed in distilled water for 24 hours. After immersion, the samples were removed, wiped dry, and weighed again. Water absorption was calculated using the formula:

$$\text{Water Absorption (\%)} = \frac{\text{Wet mass} - \text{Dry mass}}{\text{Dry mass}} \times 100 \quad (3)$$

Apparent Porosity:

The apparent porosity (AP) was measured to determine the pores present in our prepared samples. The membranes were first weighed in air followed by suspending them in water to measure the suspended weight. The membranes were then soaked in water for 24 h, removed from the water, and measured again for the soaked weight:

$$\text{Apparent Porosity (\%)} = \frac{W_s - W_A}{W_s - W_{sw}} \quad (4)$$

Where W_A is the weight in air (g); W_s is the soaked weight (g); and W_{sw} is the suspended weight (g) (Murchana, and Mihir, 2021).

Scanning Electron Microscopy (SEM):

The morphology and the microanalysis of the clays and blended additives samples were determined using an ultra-high resolution field emission electron microscope. The pulverised clay samples were coated with graphite. The sintered samples were examined using an extremely high-resolution field emission grid electron microscope. Particle images were obtained with a secondary electron detector.

RESULTS AND DISCUSSION

The chemical compositions of the Lankavri and Kpantinapu clays are given in Table 1. The chemical composition of the samples revealed that the major constituents are silica (SiO_2) and alumina (Al_2O_3). It was observed that the silica content in Kpantinapu clay is higher than that of Lankavri clay; although both are above 50%, while the alumina content is higher in Lankavri clay. Iron oxide in both is less than 10% while other elements are in a small proportion. The values are within the range of acceptable values for typical foundry clays (Kagonbé et al., 2021; Yanné et al., 2028; Murray, 2006; Sousa et al., 2017).

Table 1: Chemical Compositions of Itchi and Obukpa Clays (%)

Constituents	SiO_2	Al_2O_3	FeO_3	CaO	MgO	K_2O	S	TiO_2	L.O.I
Lankavri	58.53	13.96	9.46	1.72	0.65	0.86	0.03	0.02	9.08
Kpantinapu	73.92	10.56	2.65	0.38	0.21	0.11	0.02	0.03	3.77

LINEAR SHRINKAGE

Figures 1 – 3 show the plots of linear shrinkage against firing temperatures for coconut shell, cow bone and rice husk respectively. Linear shrinkages generally reduce as firing temperature increases. Shrinkages increase because of the evaporation of pore water and other volatile matter. This trend continues till a maximum is reached and thereafter a decrease is noticed as densification, resulting

from localized melting ensues (Yaroet al., 2009). In this present case, 900°C appears to be the maximum temperature beyond which a reduction in shrinkage is noticed. Consequently, close observation of the plots reveals that the 10 % admixture content in each case showed the best shrinkage values, but in comparative terms, the 10 % coconut shell admixture presented the best among the three additives.

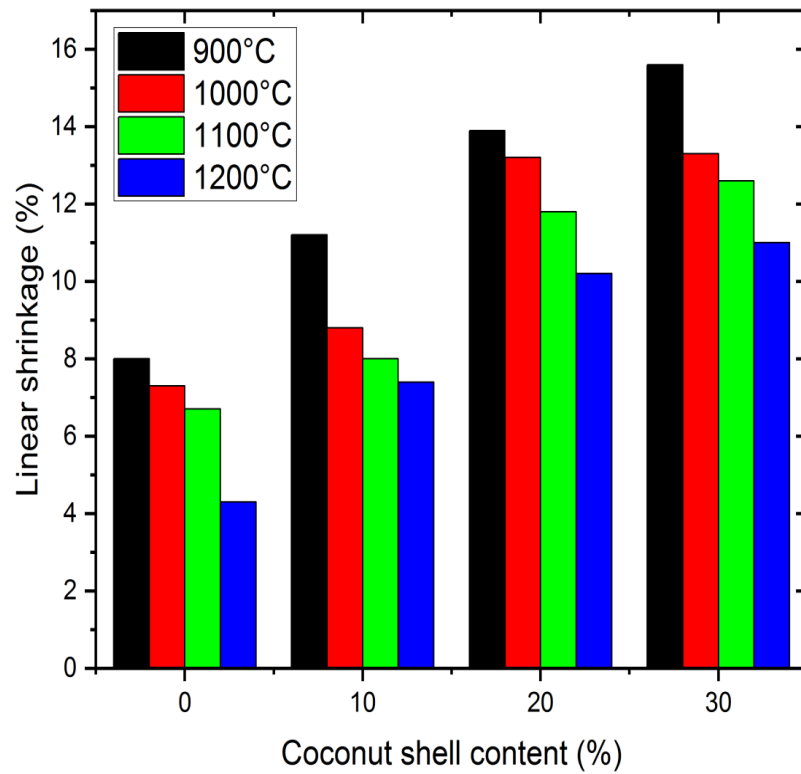


Fig.1: Plot of linear shrinkage against coconut shell contents at various firing temperatures.

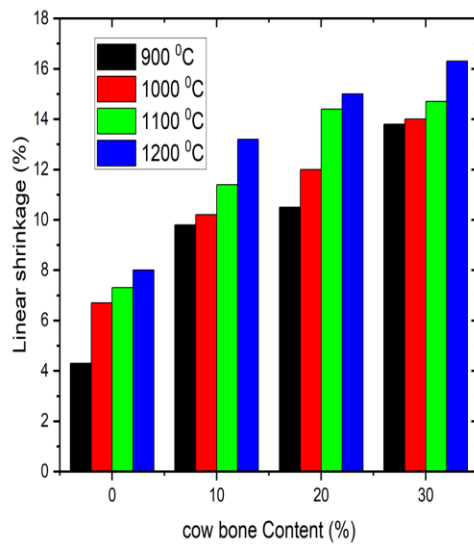


Fig.2: Plot of linear shrinkage against cow bone contents at various firing temperatures.

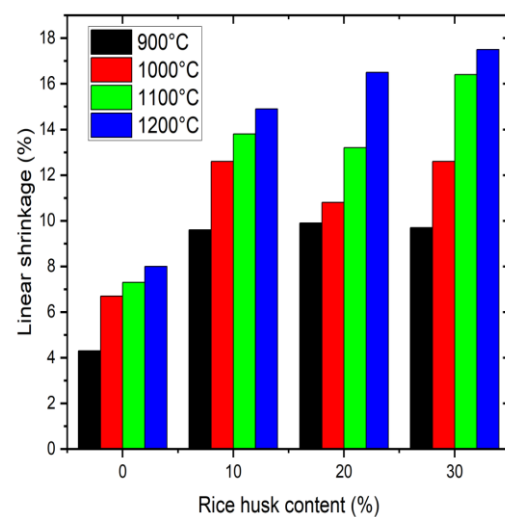


Fig.3: Plot of linear shrinkage against rice husk contents at various firing temperatures.

Bulk density

Figures 4, 5 and 6 represent the plots of bulk densities against admixture contents at various firing temperatures for coconut shell, cow bone and rice husk ashes respectively. The relationship between bulk density and firing temperature is complex but in general, their relationship is linear up to a certain temperature (above 1315°C) beyond which an inverse relationship is noticed (Hasan *et al.*, 2023). Based on the foregoing, the admixture ashes each obeyed this trend indicating that the bulk densities increased as firing temperature increased. This is attributed to reduced water content, higher particle fusion and reduced porosity (Borieset *al.*, 2015). A critical look at the plots shows that the 10 % admixture content in each of the additives was closer to the higher values of the raw clay itself. When compared, however, the coconut shell presented the highest values.

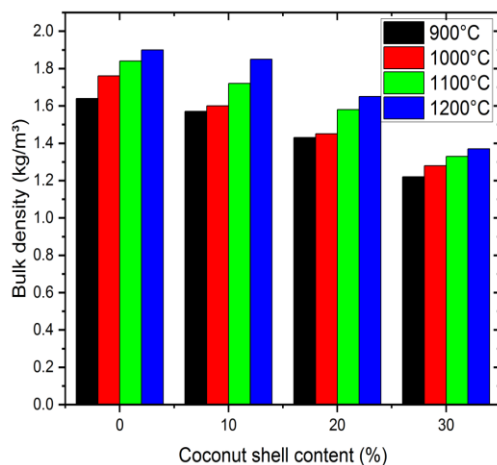


Fig.4: Plot of bulk density against coconut shell contents at various firing temperatures.

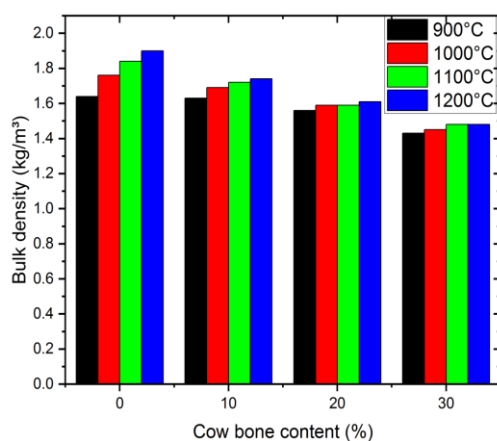


Fig.5: Plot of bulk density against cow bone contents at various firing temperatures.

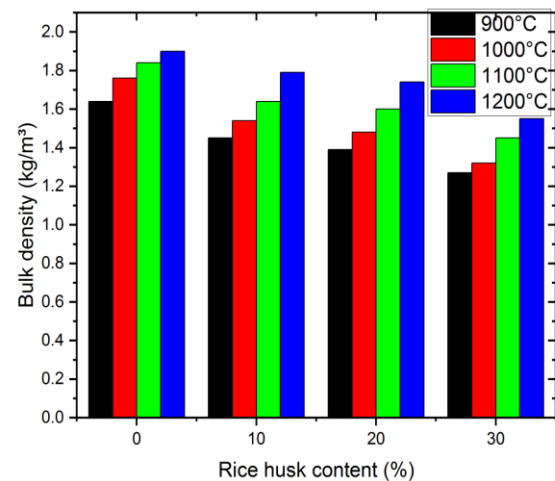


Fig.6: Plot of bulk density against rice husk contents at various firing temperatures.

Apparent Porosity

The plots of the apparent porosity against admixture contents at varying firing temperatures are shown in Figures 7, 8 and 9 respectively for coconut shell, cow bone and rice husk ashes. Theoretical assertions agree that apparent porosity initially increases as firing temperature increases because of the burning off of volatile matter, approaching a maximum at a certain temperature due to the closure of the pores arising from localized melting and interparticulate fusion (Houet *al.*, 2016; Hammelet *al.*, 2014; Hadi and Hussein, 2019). When juxtaposed with the bulk density Figures, the results tend to agree with theoretical views that the more porous a material is, the less dense it becomes, a kind of inverse relationship. A cursory look at the plots reveals that the 10 % admixture content of each of the additives was the best, with the coconut shell ash manifesting the least apparent porosity values and is therefore adjudged the best admixture among the three.

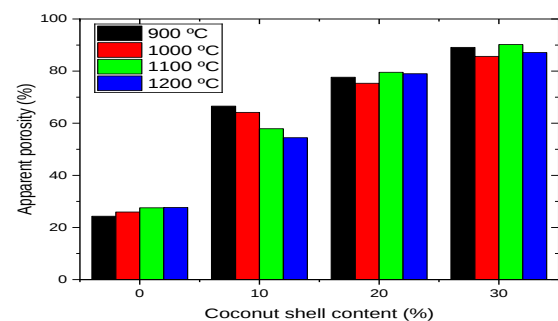


Fig. 7: Plot of apparent porosity against coconut shell contents at various firing temperatures.

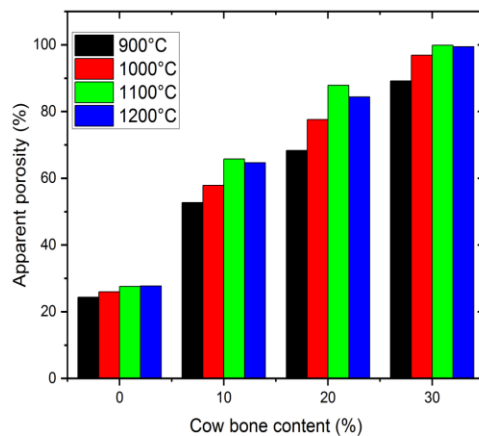


Fig. 8: Plot of apparent porosity against cow bone contents at various firing temperatures.

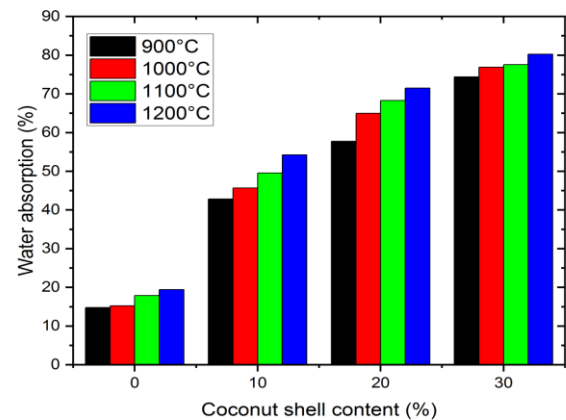


Fig. 10: Plot of water absorption against coconut shell contents at various firing temperatures.

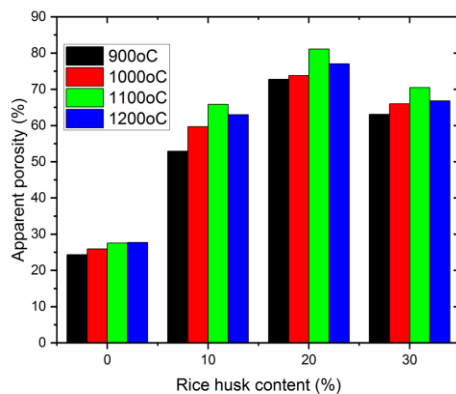


Fig. 9: Plot of apparent porosity against rice husk contents at various firing temperatures.

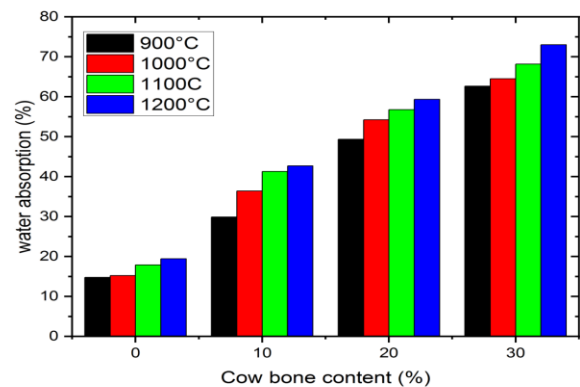


Fig. 11: Plot of water absorption against cow bone shell contents at various firing temperatures.

% water Absorption

It is already an established theoretical framework that water absorption is directly related to apparent porosity in the sense that the more apparent porosity, the more the water absorption coefficient (Rafikullahet *al.*, 2017). This implies that as firing temperatures increase, the pores close up due to localized melting, leading to the overall reduction in pore volume. Figures 10, 11 and 12 represent the plots of water absorption coefficients against admixture contents at various firing temperatures. Expectedly, coconut shell ash manifested the lowest water absorption coefficient at 1000°C admixture content among the three organic additives studied, making it the best additive.

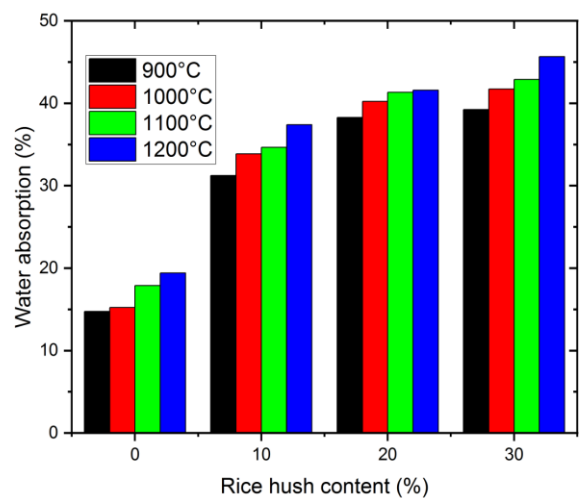


Fig. 12: Plot of water absorption against rice husk contents at various firing temperatures.

Microstructural Analysis

Figure 13 (a-e) depicts the Scanning Electron Microscope (SEM) display of the pure clay and those of 10 % and 20 % admixtures of coconut shell and cow bone ashes fired at 1200 °C each. These percentage compositions of the admixtures were chosen based on the physico-chemical properties results already established.

From the figure, the SEM result for the pure clay sample showed large grains of the various minerals present with limited pores. However, the introduction of the additives resulted in some grain refinement as a result of particle dispersion. A critical examination of the SEM in conjunction with other physico-chemical properties shows that the pure clay presented the best results followed by the 10 % admixtures of each of the additives. Correlatively therefore, the 10 % coconut shell admixture showed an SEM result close to the pure clay. Under this premise therefore, it is correct and much so to agree that if and only if necessary, the maximum percentage of the admixture to add is 10 %, while the coconut shell is the most preferred in this consideration.

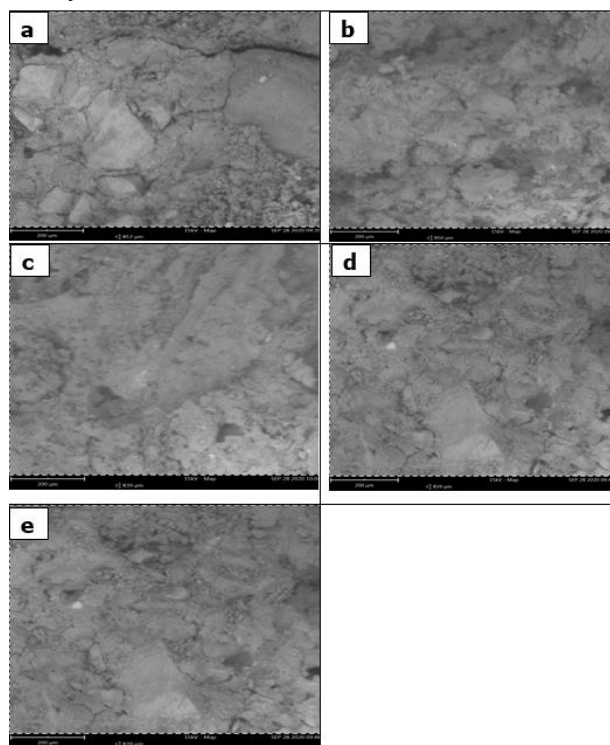


Fig.13: Scanning Electron Microscope Analysis of (a) Blended Lankavri and Kpantinapu clay, (b) 10 % coconut shell blended with Lankavri and Kpantinapu clay, (c) 20 % coconut shell blended with Lankavri and Kpantinapu clay, (d) 10 % cow bone blended with Lankavri and Kpantinapu clay and (e) 20 % cow bone blended with Lankavri and Kpantinapu clay.

CONCLUSION

The Lankavri and Kpantinapuclays have been successfully studied by the using agricultural waste ashes of coconut shells, cow bones and rice husks. These agricultural wastes were found to have some significant influence on the physico-chemical properties of both clays, albeit not so positively as it was observed that the additions rather reduced the values of the properties from those of the pure clays (Zouaouiet *al.*, 2017; Klein, 1993) Invariably, a 10 % admixture content of each of the agricultural waste showed closest properties to those of the pure clays. When compared, coconut shell presented the best of these properties, followed by cow bone and the least being rice husk ash.

It can be concluded that both Lankavri and Kpantinapuclays are quite suitable for industrial uses on their own, particularly for lining metal processing furnaces. For purposes of recycling agricultural wastes to ensure environmental safety and conservation, the use of agricultural wastes like coconut shells, cow bones and rice husks could be of value but not more than the threshold value of 10 % of each.

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