Optimization of the Quantity of Wood Ash Addition on Kaolinitic Clay Performance in Porcelain Stoneware Tiles.

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ABSTRACT

The effect of wood ash additions on the properties of porcelain stoneware tiles was investigated. Wood ash additions in the range of 0–40 wt% was added into the tile body composition, wet milled, spray dried, shaped and fired at 1200°C. The water of absorption improved with increasing wood ash content and reached maximum when 25% wood ash was used; and with greater addition, it decreased from this maximum value but increased in relation to the other values before the maximum. Permeability kept decreasing with increasing wood ash content. The Flexural strength decreased with increasing wood ash content and reached maximum when 5wt% wood ash was used, and with greater additions it decreased. The tiles with 5 wt% wood ash had improved flexural strength; young's modulus, compressive strength and permeability compared to the conventional tiles; and conform to all other properties as per EN standard specification. It also had the lowest apparent porosity and water absorption. It was observed that 5 – 10% wood ash addition in kaolinitic clays was the best ratio that gave the desired combination of opposing qualities of strength and density, and thus the optimum mechanical properties.

(Keywords: wood ash, stoneware tiles, kaolinitic, porcelain, permeability, porosity, clays)

INTRODUCTION

The ceramic industries are the major users of clay. These industries used about 70% of all clays marketed in the crude or beneficiated form and those marketed only as finished products. The white ware industries are considered to produce such products as dinner ware, sanitary ware, electrical porcelain, floor and wall tile, art pottery, spark plugs, chemical and refractory porcelain as well as other products. These products are formed by a wide variety of methods including sand casting, jiggering, extruding, power pressing and hand molding. Most of these products are composed of a mixture of kaolin, ball clay and ground non-clay materials including feldspar, quartz, talc and others [1].

Wood ash is the inorganic and organic residue remaining after combustion of wood or unbleached wood [2]. When ash is produced in industrial combustion systems, the temperature of combustion, cleanliness of the fuel wood, the collection location, and the process can also have profound effect on the nature of the ash material. Therefore, wood ash composition varies depending on geographical location and industrial processes. This makes testing ash extremely important.

Wood ash is a solid residue of the combustion of sawdust or wood in air and is composed of carbonates and oxides of metals, e.g., calcium and potassium, originally compounded in the plant's woody tissues that are present in the residue. The major elements in wood ash are calcium, potassium and magnesium, while sulphur, manganese and phosphorous are present at around 1% and iron, aluminum, copper, zinc, sodium, silicon and boron are present in relatively smaller amounts [3, 5]. The chemical composition of wood ash are mainly carbonates and oxides of the alkali metals, namely $CaCO_3$, $K_2Ca(C0_3)_2$, $Ca(OH)_2$, MgO, CaO, $Ca_4Mn_3O_{10}$, K_2SO_4, and others.

Many sources of wood ash from USA and Canada have their specific gravity between 1.6 and 2.8 and unit weight between 365 and 980kgm^{-3} [6, 7]. They have also found the major elements in the wood ash to be carbon, calcium, potassium, magnesium, phosphorus and sulphur, all in various proportions. In its chemical composition, they found present in wood ash from different wood types SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, TiO_2, K_2O, SO_3, organic matter, moisture available alkali, all with significant variations.

The specific gravity of wood ash obtained from a bakery in Minna, Niger State, Nigeria to be 2.13 and the bulk density 760kgm^{-3} and his analysis showed the chemical constituents as SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, TiO_2, K_2O, SO_3 and organic matter (loss of ignition LOI= 27%) [8]. The incorporation of residues into production processes reduces costs and creates new business opportunities, besides reducing the volume of raw material extraction, preserving limited natural resources. The use of industrial residues in the ceramic materials manufacturing process can contribute to a reduction in the raw materials costs, and also a lessening of the negative environmental impact from the disposal of the wastes in landfills [4].

MATERIALS AND METHOD

The clay samples and three non-clay materials (wood ash, feldspar as flux, and quartz as filler) were used in formulating the porcelain specimens. The raw materials were collected from various locations in Abeokuta (Ogun State, Nigeria). The clay were collected from Abiola-way and Ilese Awo, while the wood ash was collected from Camp area of Abeokuta, the feldspar and quartz were collected from Egbado area of Ogun state, Nigeria. The porcelain body was formulated as seen in Table 1: K1 – K9 represents kaolinitic clay batches.

Each of these batches were initially sun dried in open air, then manually and gently crushed in order to reproduce particles without damaging the crystal lattices. The crushed samples were then sieved using 80mesh to ensure that the particle size is less than 2µm. Moisture was added until the samples became plastic enough to be pressed manually. The slurries were dried and disintegrated. The dried powders were thoroughly mixed with water and cylindrical rods (30mm diameter x 40mm height) were prepared using compaction by manual pressing. The compacted rod was dried at 110 °C to reduce the moisture content, and then fired at a temperature of 1200°C for a soaking period of 2hrs at a test speed of 040.00mm/min in an electric furnace.

The crystalline phases in raw materials and fired samples were identified by XRD techniques using Radicon MD10, Version 2.00.1, CuKα radiation at 40Kv/40mA from 16°<2θ<72°, exposure time of 1200/1200sec. The micro structural features of sintered specimen containing 5wt% and 10wt% wood ash was examined by SEM (JEOL JSM840) with an EDX attachment. The bulk density and water absorption of the tiles were measured by a water displacement method. The chemical analyses of the materials was determined using Buck scientific 205 Atomic Absorption Spectrophotometer, A Universal Testing Machine (Tenstometric) was used to determine the compressive strength.

Table 1: Compositions of Nine Batches of Porcelain Specimen.

CONSTITUENTS	Clay (wt %)	Wood ash (wt %)	Feldspar (wt %)	Quartz (wt %)
K1	50	0	20	30
K2	45	5	20	30
K3	40	10	20	30
K4	35	15	20	30
K5	30	20	20	30
K6	25	25	20	30
K7	20	30	20	30
K8	15	35	20	30
K9	10	40	20	30

RESULTS AND DISCUSSION

The chemical analyses of the raw materials are given in Table 2. The Fe_2O_3 is high compared to other impurities present. It was generally observed that variations in the chemical compositions of the selected clay in Abeokuta can be attributed to the compositional differences in the source areas and variations in the residual supply unit.

An observation of Table 2 indicates that the loss on ignition varies from 8.95 wt % to 13.73 wt % due to water vapor from dehydroxylation reactions in the clay minerals, carbonate decomposition into CO_2 and oxides as well as burning out of organic matters. High alumina content was observed in the kaolinitic clay. The high aluminum oxide content of the kaolinitic clay as shown in Table 2 indicates that clays rich in alumina are associated with high clays in the free state, as alumina are associated with high clay mineral content in the combined state as alumina-silicates and very seldom is found in clays in the free state. The organic oxides detected in wood ash as shown in Table 2 correlates with the one reported by [7]. Fly ash also contains almost all organic oxides contained in wood ash which was reported to have effect on properties of porcelain stoneware tiles [9].

The presence of alkali oxides in all the selected clay deposits in Abeokuta as shown in Table 2 indicates their excellent fluxing ability during firing at comparatively low temperature, to form glasses of complex composition towards giving a vitreous structure to ceramics bodies. The kaolinitic clay (0.05wt %) has a low lime composition. These oxides in clays act as mild fluxes (i.e., they combine with the oxides of alumina and silica on firing, to form eutectics and so reduce the vitrification temperature and refractoriness of the clay) [8, 9].

Figures 1 to 7 show the physico-mechanical properties of both green and vitrified stoneware tile of the clay (kaolinitic) in relation to wood ash content as shown in Tables 4.

The firing shrinkage indicates the fusibility of the porcelain body and a high shrinkage means lower melting point [9]. From the result presented in Table 4 the linear shrinkage of the vitrified tiles (Figure 1) decreased with gradual fluctuation (abnormal trend) for the kaolinitic clay batches with wood ash content. The highest linear shrinkage was at 15% and lowest at 10% wood ash content.

From Table 4 it is observed that percent linear shrinkage (%LS) of kaolinitic clay at 1200°C is low. It is more advantageous to use the clays with lower percent shrinkage for wall tile compositions. This may be due to the reason as the wood ash replaces the kaolinitic clays, the compositions contain progressively less of the fluxing oxides, therefore the viscosity rises and the rate of consolidation is reduced. It was observed that the wood ash addition to the kaolinitic clay causes progressive increase and a decrease at 30% wood ash content and back to increase at 35% wood ash in the water of absorption of the mix.

It can be observed from Table 4 that flexural strength value generally decreases in kaolinitic clay samples with wood ash content from 1.41N/mm^2 to 0.11 N/mm^2 at 35% wood ash. This is due to the non-plastic behavior of wood ash, which is substituting for the plastic clay.

Table 2: Chemical Analysis of Raw Materials.

Constituents (Wt %)	CaO	MgO	K_2O	Na_2O	ZnO	MnO_2	Cu_2O	Fe_2O_3	SiO_2	Al_2O_3	$CaSiO_3$	L.O.I.
Kaolin	0.05	0.02	0.03	0.02	0.12	0.09	0.01	0.54	53.60	36.57	ND	8.95
Feldspar	0.06	0.03	0.04	0.02	0.12	0.09	0.01	0.54	77.22	9.21	ND	4.24
Quartz	0.97	0.08	0.16	0.01	1.06	1.88	0.02	0.95	88.39	0.83	ND	5.65
Wood ash	12.93	0.65	4.54	0.67	0.44	2.94	0.12	6.13	27.82	ND	30.03	13.73

L.O.I: Loss on ignition, ND: Not Detected

Table 3: Quantitative Phase Analyses of Wood Ash.

PHASES	VOLUME %
β- Quartz	21.3
Crystobalite	57.8
Zoisite (syn)	14.6
Wollastonite	6.3

Table 4: Physico-Mechanical Properties of both Green and Vitrified Stoneware tile of Kaolinitic Clay in Relation to Wood Ash Content.

Ash %	0	5	10	15	20	25	30	35	40
L.S %	6.20	4.70	3.70	16.60	4.10	9.30	15.80	4.50	13.70
W.A %	0.12	0.11	0.13	0.15	0.17	0.21	0.19	0.19	0.20
F.S N/mm^2	76.02	61.00	50.00	42.96	26.00	22.75	17.37	16.00	11.89
Y.M	165.52	162.55	107.18	105.53	56.86	28.86	43.10	25.46	36.33
C.S N/mm^2	9.40	8.29	4.05	3.31	1.72	1.15	1.10	0.75	1.07
PM %	150.07	148.19	134.09	129.96	111.26	66.12	56.34	49.98	45.76
B.D g/cm^3	2.61	2.78	2.93	2.98	2.94	2.89	2.57	2.81	2.64
A.P %	3.42	3.61	4.07	4.22	4.29	4.41	4.65	4.33	4.01

L.S – Linear shrinkage, W.A- Water of Absorption, F.S- Flexural Strength, Y.M- Young's Modulus, C.S- Compressive Strength, PM-Permeability, B.D- Bulk density, A.P- Apparent Porosity.

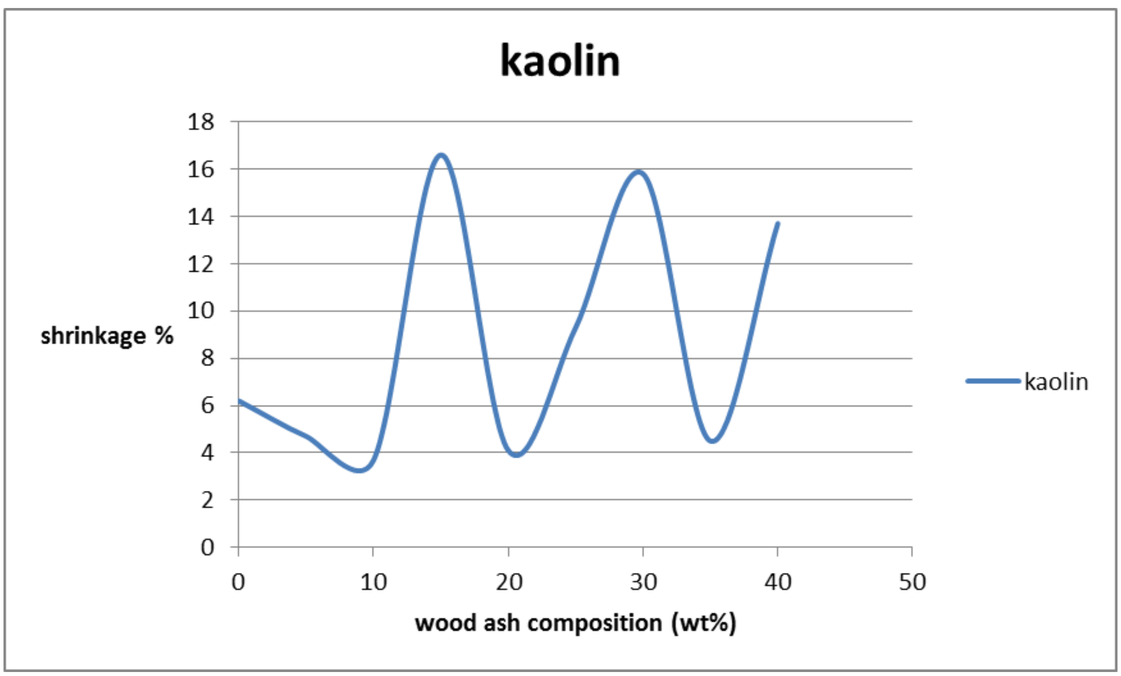

Figure 1: Linear Shrinkage (L.S.) against Wood Ash Composition.

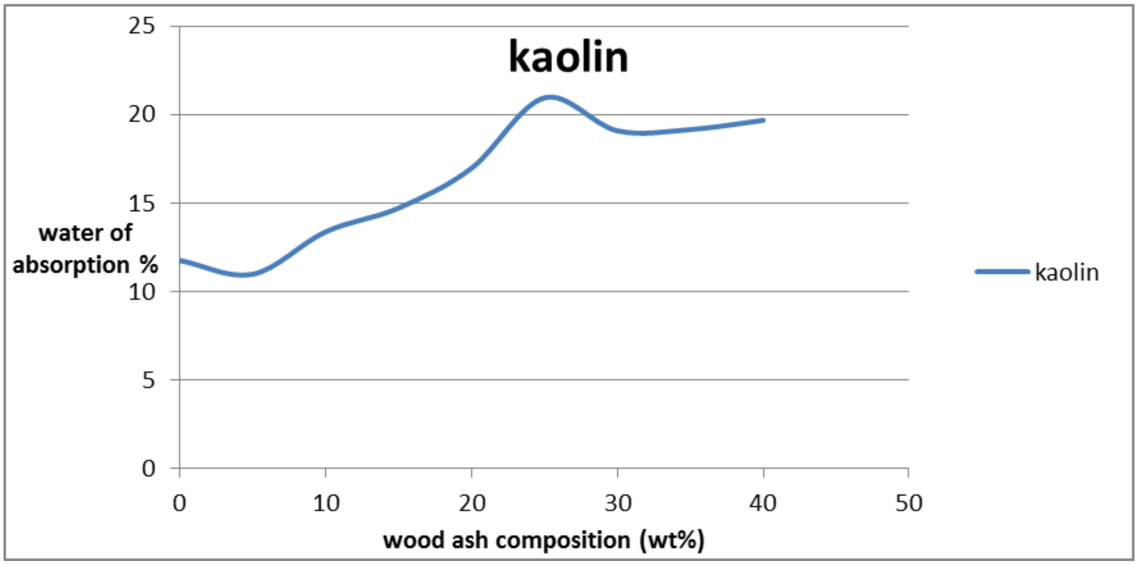

Figure 2: Water of Absorption (W.A.) against Wood Ash Composition.

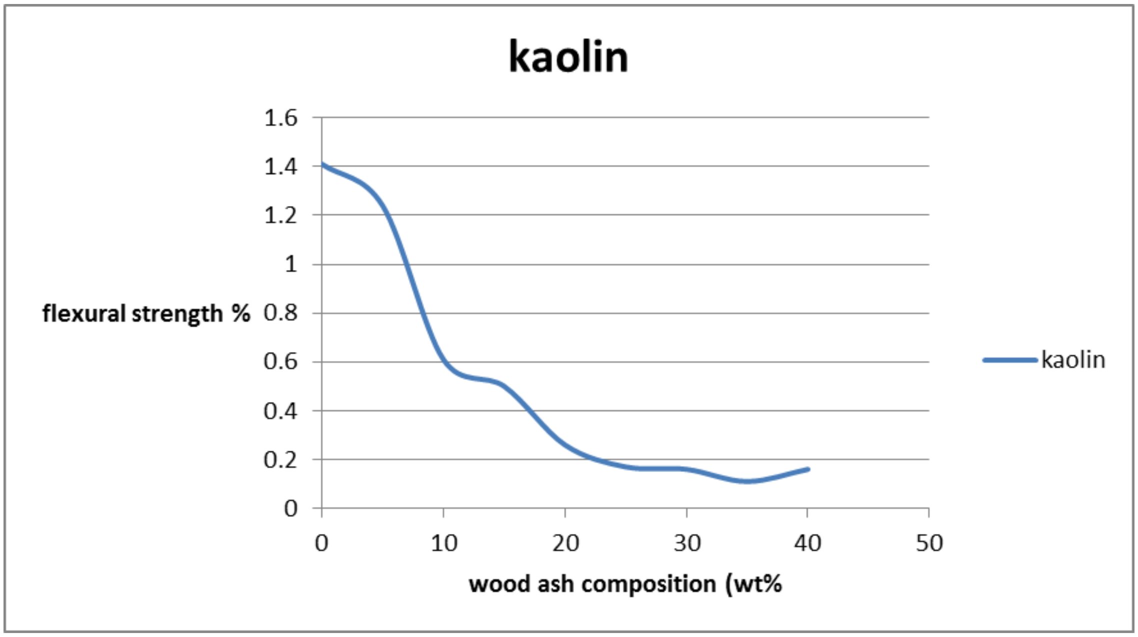

Figure 3: Flexural Strength against Wood Ash Composition.

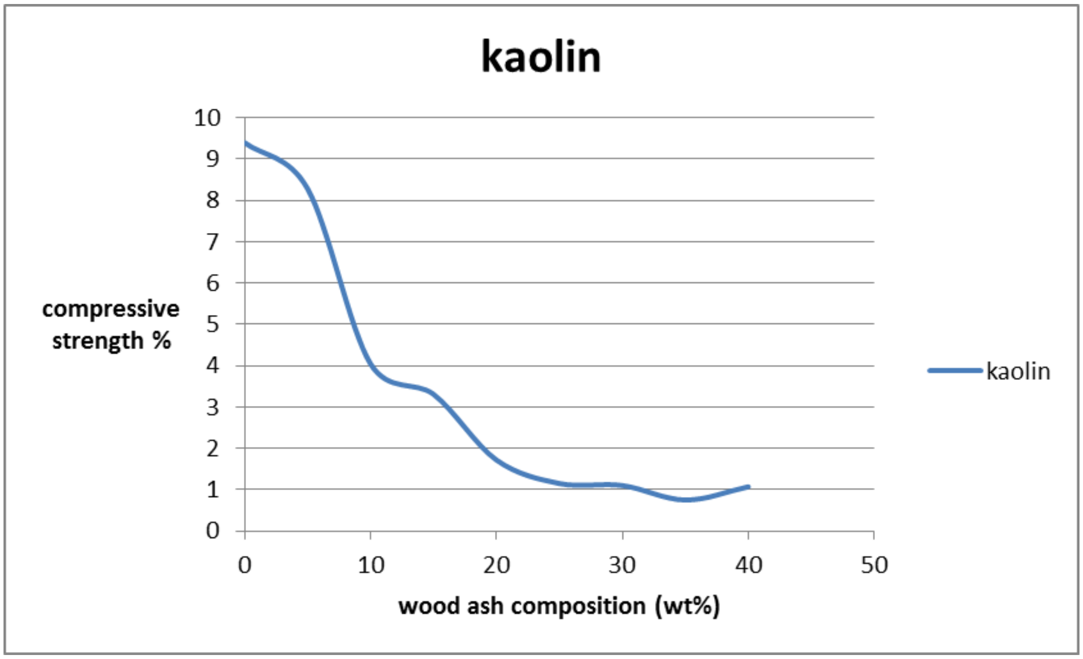

Figure 4: Compressive Strength against Wood Ash Composition.

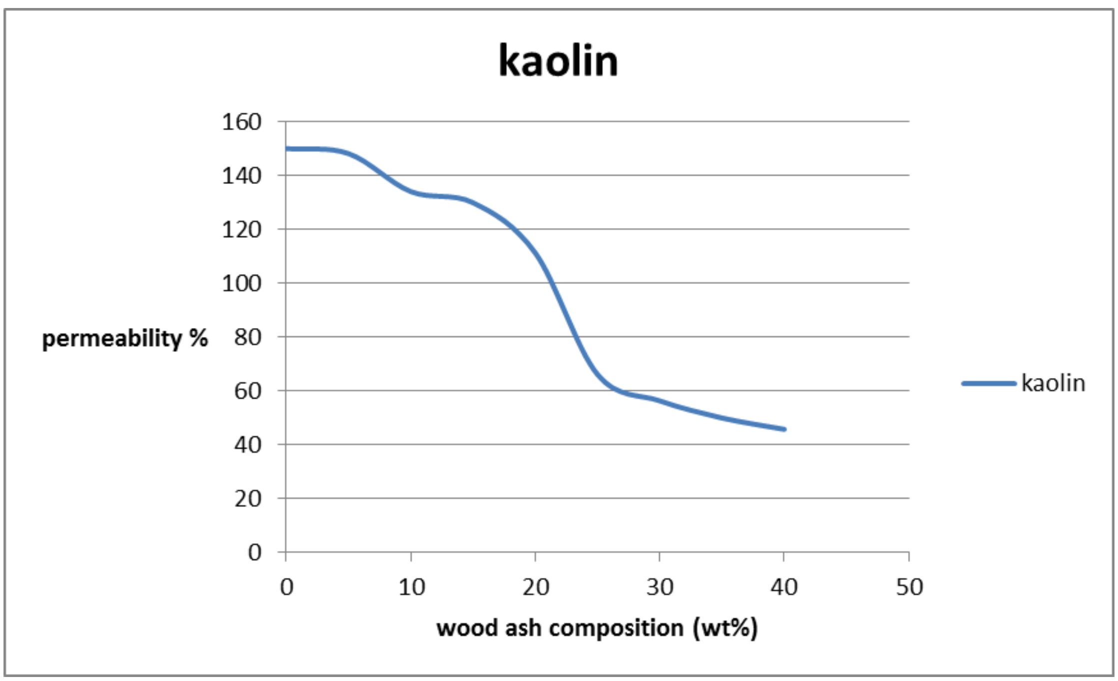

Figure 5: Permeability (PM) against Wood Ash Composition.

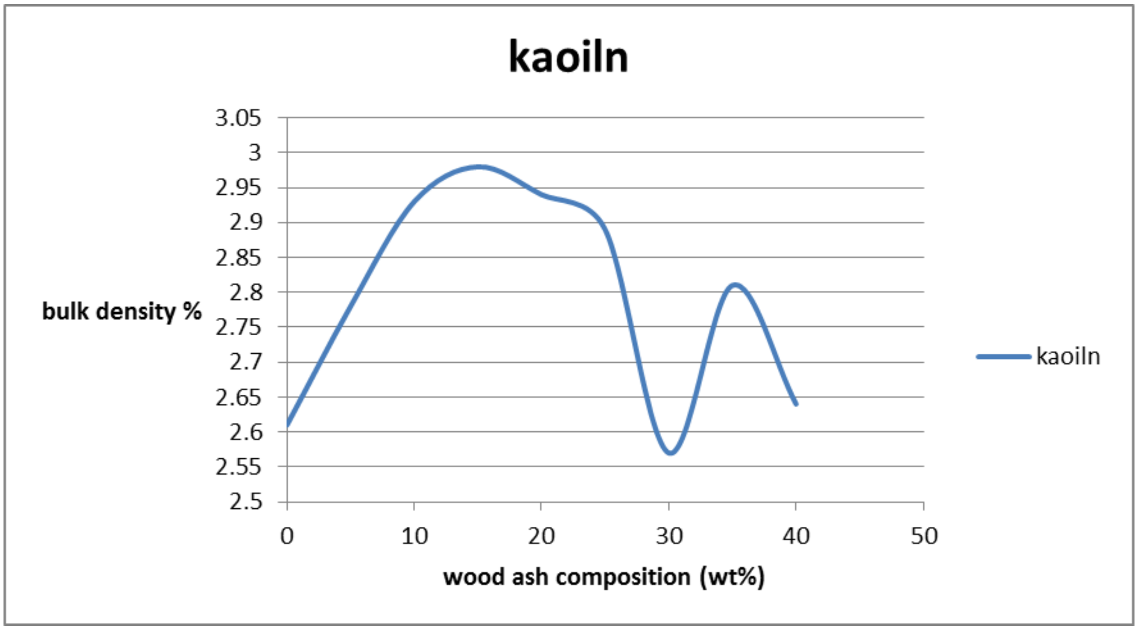

Figure 6: Bulk Density (B.D.) against Wood Ash Composition.

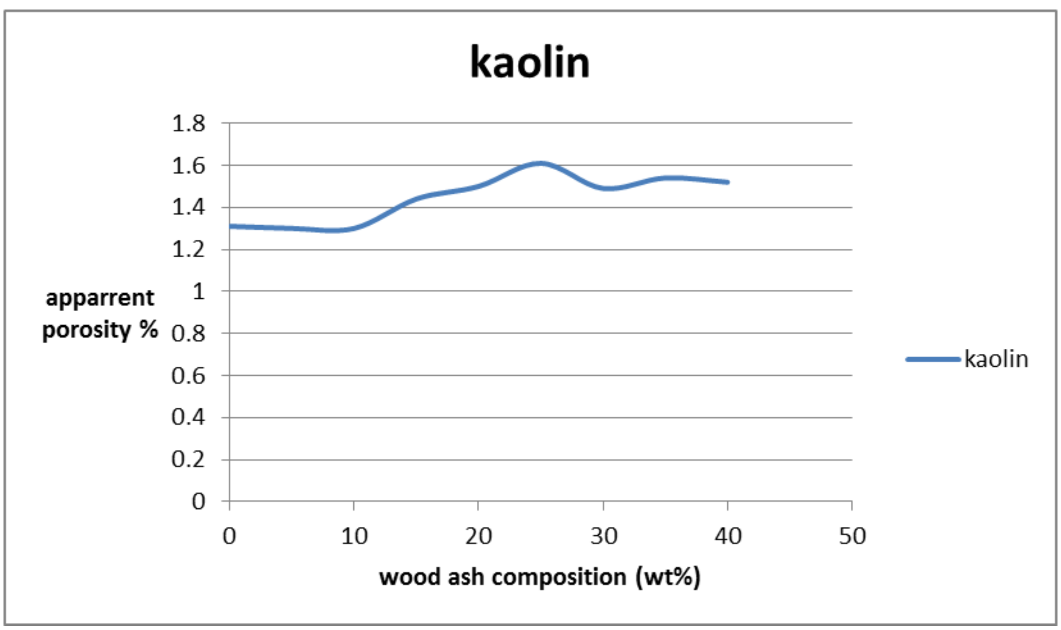

Figure 7: Apparent Porosity against Wood Ash Composition.

It can be observed from the table that the young's modulus initially decreases gradually in the kaolinitic clay sample up to 25% wood ash content after which it exhibited successive increase and decreases then increase at 40% wood ash- it has its maximum value at 5% wood ash content.

It can be observed from the tables that the bulk density value initially increases up to 15% wood ash content after which it decreased up to 30% and then increased and decreased at 40% wood ash value. It can be observed from the tables that the compressive strength value initially increases up to 25% wood ash content after which it exhibited successive decrease and increase up to 40% wood ash content.

CONCLUSION

The tremendous effect of wood ash on the mechanical and other properties of porcelainized stoneware tile as the wood ash content varies was found to be an important tool for designing porcelainized stoneware tiles and hence present wood ash as a suitable local additive that can modify properties of clays and result in better porcelain qualities.

From the test results, it can be deduced that the effect of the addition of wood ash results in the production of light weight and more porous products, but the very high temperature 1200°C to which the firing was taken ensured completion of the pozzolainic reactions instituted by the wood ash and the production of dense compounds acting as filler within the pores of the porcelain mass.

The addition of wood ash was also found to improve the plasticity of clays and acts as reinforcing agent reducing concentrated crack that can lead to breakage within the raw porcelain. Upon firing, the fiber of the wood ash burns out thus assisting in even firing of porcelain and minimizing the development of high temperature gradient within it, a phenomenon which may lead to firing crack. The pores left behind when the wood ash burns out reduce unit weight of the porcelain and improves thermal characteristics of the porcelainized stoneware tiles. It was also found that the higher the wood ash content in porcelain the lower their strength and density, and the lower the permeability.

5 – 10% wood ash in clays is the best ratio that gives the desired combination of opposing qualities of strength and density, thus the ratio that gives the optimum mechanical and other properties.

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