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INVESTIGATIVE STUDY OF THE EFFECTS OF CERTAIN ADDITIVES ON SOME SELECTED REFRACTORY PROPERTIES OF ANT-HILL CLAY FOR FURNACE LINING

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ABSTRACT

The choice of appropriate locally sourced refractory materials for lining of locally produced furnaces has remained a major concern in which numerous efforts has been put in place to enhance the performance of the local contents of furnace lining materials. This study investigates the effects of certain additives such as Pulverized Glass Wastes (PGW) and Bentonite on some selected refractory properties of ant-hill clay. 100% finely-ground ant-hill clay, clean water and proportionate amount of Bentonite and PGW were manually mixed, consolidated and oven-dried at 110 °C for a period of 8 hours at varying additives percentages. Compressive strength, apparent porosity, permeability, filtration rate, thermal conductivity and bulk density were *experimentally determined... The results showed that the compressive strength, bulk density and thermal conductivity of Ant-hill clay increased significantly on addition of additives while there was corresponding decrease in the values of the filtration rate, apparent porosity and permeability. These values were enhanced by Bentonite and pulverised glass waste additions to the Ant-hill clay. The test results for the compressive strength, thermal conductivity, filtration rate, apparent porosity, bulk density and permeability of no-additive clay samples are 156.4 N/m^2, 0.0028 W/m^{2}K, 0.0041cm^3/s, 0.0009 %, 6.3 g/cm^3 and 0.0012 cm/s, respectively. However, the sample-mix consisting 100% ant-hill clay with 80% PGW and 20% Bentonite produced 333.4 N/m^2, 0.0032 W/m^{2}K, 0.0037 cm^3/s, 0.00018 %, 9.5 g/cm^3 and 0.0015 cm/s as optimum values for the compressive strength, thermal conductivity, filtration rate, apparent porosity, bulk density and permeability, respectively. Therefore, 80%PGW/20%Bentonite additives gave the optimum results for the production of refractory clay blocks for furnace lining.*

Keywords: Ant-Hill, Apparent porosity Bentonite, Bulk density, Compressive Strength, Pulverised Glass Waste

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1. INTRODUCTION

A refractory material is one that retains its strength at a high temperature condition [1]. Refractories are non-metallic materials for structures or as components of systems that are exposed to a working environment above 1000°C. Refractories are utilized in the metallurgical industry as the main components for lining or insulation during furnace construction [2]. According to [3], a refractory is any material that can withstand the effect of abrasive or corrosive solids, liquids, or gases at elevated temperature. Some other general requirements of a refractory material are the ability to withstand sudden changes in temperatures, conservation of heat and low co-efficient of thermal expansion [2, 3].

Ant-hills are mounds of soil formed by ants or termites during the process of digging or building their nest. Ants are known to transport huge quantities of materials from within the soil and depositing it on the surface. Some of the Ant mould hills are about 5 meters tall and 7 meters in diameter [1, 2]. However, clay which forms the major composition of Ant-hills is a naturally occurring material which composed primarily of fine-grained materials. These materials show plasticity when the required amount of water content is added. This can be hardened when dried or fired. Clay deposits are mostly composed of clay minerals (Phyllosilicate minerals), which impart plasticity and harden when fired and or dried [4]. Pure clay, when molded, formed and fired will practically be non-porous. The existence of minute pore confers significant capillary properties on clay bodies. The pores can be created by addition of coarse particles like sand in the clay composition. The degree of porosity will however be dependent on the ratio of sand to clay in the mixture [5]. Glass is an amorphous non-crystalline material which is typically brittle and optically transparent [Citation needed]. The most common type of waste glass materials found around are drinking vessels and window glasses. Most of the readily available waste glass materials are soda-lime glass bottles, composed of about 75% Silica plus Na_2O, CaO and several other additives. Glass industries are also sources of waste glass powder which is absolutely inert and non-biodegradable. The disposal of these waste glasses produced from different glass factories has become a great environmental challenge. These materials pose a lot of threat to the environment because they can result into pollution in the nearby locality since they are majorly non-biodegradable. One solution to this menace is to recycle and convert the wastes into useful products [6].

In recent years, especially in the developing countries, researchers have focused on maximizing the use of natural clays for producing refractories which has the potential to enhance the industrialization of a nation as well as earn foreign exchange. In Nigeria, for example, many research works have been carried out on improving refractory clay blocks but none of those studies have considered the use of pulverized glass wastes and Bentonite as additives. It is important to improve the refractory properties of natural clays in order to enhance their performances and suitability for use in metallurgical furnaces. High alumina cement [7], graphite and asbestos [8], silicate binder refractory concretes with alumina binder concretes [9], silicon carbide and saw dust [10], spent graphite electrode [11], have been used and reported for the improvement of certain refractory properties of some other local Clay materials.

The aim of this study is to investigate the effects of pulverized waste glasses and Bentonite additives on the refractory properties of ant-hill clay block for furnace lining. The effects of the additives at different proportions on the thermo-mechanical properties of the ant-hill clay for furnace lining were studied.

2. MATERIALS AND METHOD

The materials used for this research work were naturally-occurring ant-hill clay, finely-grounded glass powder and Bentonite. The clay was obtained from one of the numerous ant-hills within the Ekiti State University's farms, Ado-Ekiti, Ekiti State, Nigeria (Latitude: 7° 37' 23.84" N and Longitude: 5° 13' 15.13" E). Bentonite and smoothly grinded glass powder are the additives used in this study. The Bentonite used in this work was obtained around Ureje stream in Ado-Ekiti. Also, the glass particles used were those obtained from a window glass-producing factory in Ado-Ekiti.

3. EXPERIMENTAL PROCEDURE

3.1 Chemical Analysis

The ant-hill lumps or crumbs were crushed and grounded into a fine homogenous powder. The chemical analysis of the material was conducted by X-ray diffraction (XRD) technique as indicated in Table 1. The powdered sample was tightly and carefully packed into a thin-walled glass capillary tube having uniform cross-sectional area. This is then placed in the path of a narrow beam of monochromatic X-rays.

Table1. Chemical compositional analysis of ant-hill clay

Composition	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO	Na_2O	K_2O	TOTAL
Percentage composition	59.83	33.67	2.39	0.81	0.15	0.86	0.06	2.23	100%

3.2 Material Preparation

Particle sizes range of 2.0-1.5 mm, -1.5 mm-1.0 mm and -1.0-750 µm of clay obtained from the anthill were crushed and sieved with a set of sieves. Sieving was done to separate the clay from debris, stone, leaves that can serve as contaminants in producing fine-grained particles.

The bentonite obtained from the stream was oven-dried by DHG 9053 electrical oven to remove moisture content before it was properly sieved to separate stones, debris and other sand particles that might be present in it. The obtained glass particles were crushed into powdery form. Using a weighing balance, the anthill clay used was measured and the mass used for the study was fixed at 750 g. The additives (bentonite and crushed glass powder) were measured in varying proportions (between 0% and 100%) and were mixed evenly with the fixed mass of the anthill clay; for each proportion of the additives. 100ml of water was added to the varying proportions of mixture samples of both the clay and additives. The obtained mixture was molded into several shaped specimens for experimental tests. Disc-shaped specimens were produced to investigate the thermophysical properties and cup-shaped specimens were obtained to determine the water filtrating capacity of the samples. Square-shaped specimens were produced to determine the crushing strength of the different samples having varying proportions of additives.

3.3 Refractory Properties Determined

The properties investigated on the test samples include the crushing or compressive strength, thermal conductivity, bulk density, apparent porosity, permeability, filtration rate and the chemical composition.

3.3.1 Compressive Strength Determination

The square-shaped test specimens were first allowed to dry in the open laboratory atmosphere for 48 hours to remove the moisture content from them, thereby making them suitable for further handling. The samples were oven-dried by DHG 9053 electrical Oven at 110ºC for 24 hours to ensure complete water loss. The California Bearing Ratio (CBR) machine (Model No) was used to obtain the maximum failure mode under compression. The CBR test is a penetration test for evaluation of the mechanical strength of materials such as clayey soil. The CBR value of the test sample was determined in corresponding to plunger penetrations of 2.5 mm and 5 mm as per the standard procedure (IS 2720 (Part 16)-1987) (6). The compressive forces of the respective test samples were determined by multiplying the Proving Ring Factor (PRF) of the CBR machine by their respective maximum failure loads.

Mathematically, compressive strength can be determined using Eq. (1).

$$\text{Compressive strength} = \frac{\text{Max. Failure load} \times \text{PRF}}{\text{Area of sample}} \ (\text{N/m}^2) \tag{1}$$

3.3.2 Thermal Conductivity Determination

The disc-shaped test samples were allowed to dry at 110 ºC in an oven (DHG 9053 electrical Oven) for 24 hours before thermal conductivity test was carried out. Lee's disc apparatus was utilized for this test. The heating flask was filled with water and heated up directly via a Bunsen burner set up. The sample was placed in-between the steam chest and the lower disk mounted on a retort stand where thermometers were attached to steam chest and lower disk to measure temperature T_1 and T_2, respectively, in a steady state.

3.3.3 Water-filtrating Capacity Determination

Cup shaped-like specimens were used for this test. Based on the increasing percentage order of the additives (0, 10, 20, 30 …, 90, 100%), the analysis of the filtrating capacity of the samples were taken one after the other with varying time in the order of 0, 5, 10, 15, 20, …, 90, 95, 100 minutes using a stop watch. 50 ml clean water was poured in each of the sample and a stop watch was used to determine the time taken for the given quantity of water to be filtered through the samples. The quantity of water filtered gave the idea of the volume of water retained in each of the samples.

Mathematically, filtration rate is the difference between an actual volume of water in the sample before filtration and the volume of the water filtered after filtration divided by the time taken in filtering the water as shown in Eq. (2)

$$Filtration\ rate, Q = \frac{V_A - V_F}{t_F}\ (cm^3/s) \tag{2}$$

where Q is filtration rate, $\mathrm{cm^3/s}$; V_A is actual volume of water poured into the sample, $\mathrm{cm^3}$; V_F is final volume of water after filtration, $\mathrm{cm^3}$; and t_F is time taken after filtration, s.

3.3.4 Bulk Density Determination

Bulk density is a measure of the weight of the soil per unit volume (g/cm^3). Variation in bulk density is attributable to the relative proportion and specific gravity of solid organic and inorganic particles and to the porosity of the soil. Using a digital weighing machine, the mass of the specimen were obtained. Each specimen (wrapped in a polythene bag) of varying proportions of additives was completely immersed in a displacement pan full of water. The volume of the water displaced after immersion was obtained using a measuring cylinder. With Eq. (3), bulk density can be derived.

$$Bulk\ density = \frac{Mass}{Volume}\ (g/cm^3) \tag{3}$$

3.3.5 Apparent Porosity Determination

Apparent porosity is the amount of ores within a volume of sediment or porous solid. Porosity is the percentage relationship between the volume of the pores space and the volume of the samples.

The weight of each of the dried samples was measured using a digital weighing machine. The samples were later soaked in clean water for about five minutes after which their weights were measured. Eqs. 4 and 5 illustrate how the apparent porosity can be determined by calculation.

$$Apparent\ porosity, \phi = \frac{V_p}{V_t}\% \tag{4}$$

$$\phi = \frac{(s-d)/\rho_w}{d/\rho_b} = \frac{m_w}{\rho_w} \times \frac{\rho_b}{d} \tag{5}$$

where V_p is volume of the pores space (cm^3), V_t is volume of the sample (cm^3), ρ_w is density of water (g/cm^3), ρ_b is bulk density of sample (g/cm^3), s is weight of soaked sample (N), d is weight of dry sample (N) and m_w is weight of water molecules filling the pores space (N)

3.3.6 Permeability Determination

It is the physical property of porous materials which determines the flow of fluid through the material by an applied pressure gradient. It is commonly symbolized as ‘k’. Based on Darcy’s equation; permeability of the samples was calculated using Eq. (6).

$$Q = \frac{kA}{\mu}\frac{dp}{dx} \tag{6}$$

Where $k$permeability (Darcy) is, $\frac{dp}{dx}$ is pressure gradient (atm/cm), A is cross-sectional area (cm^2), μ is viscosity of the fluid and Q is volumetric flow (cm^3/s).

4. RESULTS AND DISCUSSION

4.1. Chemical Analysis

The compositional analysis of the ant-hill clay is presented in Table 1. Based on this information, the ant-hill clay can be classified as silicious firebricks with high proportion of silica sands. The silica content of this ant-hill clay sample (59.83%) is higher than that presented by [7] (58.83%) and [8] (53.36%). These hill samples by [7] and [8] were classified as silicious and aluminous fireclays respectively. It was revealed that the clay material falls within the range of semi-plastic fireclays as reported by [12]. According to [13-14], when the chemical compositional percentage of silica is high well above 46.51% in the clay, it denotes that it will be able to withstand fairly high temperature. The alumina (Al_2O_3) content of the ant-hill clay in this study was high, meeting the required standard fr the production of ceramics, bricks, high melting clay, glass and paper when compared to the result of [13] which was lower for the production of the mentioned products above. However, the alumina content required for the production of paint was to be 37.9%. For this study, the alumina content obtained was lower than this requirement. Therefore, the ant-hill clay in this study can be useful for the production of furnace lining or bricks, ceramics, glass and so on but cannot be useful for the production of paint.

4.2. Crushing or Compressive Strength

The average values for the compressive strength of the various test samples are presented in Table 2. The compressive strength of the test samples with 100%Ant-hill/0%Glasspowder/100%Bentonite and 100%Ant-hill/100%Glass powder/0%Bentonite are 166.7 N/m^2 and 537.1 N/m^2 respectively. However, the test sample consisting 100%Ant-hill/90%Glasspowder/10%Bentonite gave the optimal value of compressive strength of 666.7 N/m^2 as compared to the compressive strength of pure ant-hill considered as a bench mark (having 0%additives) evaluated to be 156.4 N/m^2. This indicates that the Ant-hill with the highest percentage of glass powder additive possesses desirable compressive strength properties compared to that with highest percentage of Bentonite additives. This could be attributed to the fact that the adhesive forces between the clay particles are increased largely with the addition of glass powder. Also, the glass powder in the clay matrix seals the pores which act as areas of stress concentration for easy fracture of the samples. This observation was also reported by (5) and (8)

Table 2.Compressive Strength of the ant-hill clay at different percentage of additives

Sample	Ant-hill clay (%)	Percentage of additives		Max. Load Failure (N)	Compressive Force (N)	Compressive Strength (N/m^2)
		Bentonite	Glass			
1	100	100	0	9	0.23	166.7
2	100	90	10	7	0.18	129.6
3	100	80	20	8	0.2	148.2
4	100	70	30	17	0.43	314.8
5	100	60	40	22	0.55	407.4
6	100	50	50	15	0.38	277.8
7	100	40	60	16	0.4	296.3
8	100	30	70	28	0.7	518.6
9	100	20	80	18	0.45	333.4

10	100	10	90	36	0.9	666.7
11	100	0	100	29	0.73	537.1

*Compressive strength for no additive is 156.4 N/m^2

4.3. Thermal Conductivity

Based on the results of thermal conductivity test presented in Table 3, the thermal conductivity of anthill-clay with no additives is 0.0028W/m^{2}K while the test sample with 80% glass powder and 20% Bentonite gave the least value of thermal conductivity of 0.0032W/m^{2}K. This value is considered optimal and desirable for the thermal conductivity properties of a material of choice for furnace lining.

Table 3. Thermal conductivity of the ant-hill clay at different percentage of additives

Sample	Ant-hill Clay (%)	Percentage of additives		Thermal conductivity (W/m^{2}K)
		Bentonite	Glass	
1	100	100	0	0.0037
2	100	90	10	0.0041
3	100	80	20	0.0047
4	100	70	30	0.0048
5	100	60	40	0.0039
6	100	50	50	0.0046
7	100	40	60	0.0044
8	100	30	70	0.0042
9	100	20	80	0.0032
10	100	10	90	0.0038
11	100	0	100	0.0043

*Thermal conductivity of no additive Ant-hill clay is 0.0028W/m^{2}K

4.4. Water retention rate, Filtration rate, Bulk density, apparent porosity and Permeability

These parameters are considered as important properties that affect the strength of refractory materials as well as their insulating ability. The values of the water-retentive capability and filtration rate of the test samples are presented in Tables 4 and 5, respectively. As indicated on Table 4, the water retention capability of the test samples was greatly imparted via the introduction of bentonite and glass powder additives. Table 5 showed that the filtration rate was least with a value of 0.0037cm^3/sec when the proportion of additives in the sample is 80% glass powder and 20% bentonite.

Table 4. Water retaining of the ant-hill clay at different percentage of additives

Time (min)	Volume of water retained (ml)											
	Bentonite (%)	100	90	80	70	60	50	40	30	20	10	0
	Glass (%)	0	10	20	30	40	50	60	70	80	90	100
0	-	50	50	50	50	50	50	50	50	50	50	50
5	-	39	37	36	37	38	39	40	41	42	43	40
10	-	40	36	36	37	37	38	38	40	41	42	37
15	-	38	34	35	36	37	38	38	38	41	46	37
20	-	36	34	34	35	36	36	37	35	41	38	35
25	-	34	33	32	34	36	35	34	33	39	37	33
30	-	32	33	31	33	35	34	33	32	38	36	32
35	-	31	32	29	31	33	32	31	30	36	34	30
40	-	30	32	29	30	33	29	30	27	36	33	28
45	-	29	31	28	29	32	28	30	27	36	32	27
50	-	28	31	27	28	31	27	29	26	35	31	26
55	-	27	30	26	28	30	26	28	25	34	31	25
60	-	26	29	25	27	29	25	27	24	33	30	24
65	-	26	28	25	26	28	23	27	24	33	29	23
70	-	25	27	24	25	27	22	26	23	32	28	22
75	-	24	26	23	24	26	21	25	22	31	27	21
80	-	24	26	23	23	26	20	25	22	30	26	20
85	-	24	26	23	22	26	19	25	21	28	25	19
90	-	23	25	23	21	25	18	24	20	27	24	18
95	-	22	24	22	20	24	17	23	19	26	24	17
100	-	21	23	22	19	23	16	22	18	26	23	17
105	-	19	21	20	18	19	15	20	17	25	22	16
110	-	18	20	19	17	19	14	19	16	24	20	15
115	-	17	19	18	16	18	13	18	15	23	19	14
120	-	16	18	17	15	18	12	17	14	23	18	13
125	-	15	18	16	15	17	11	14	13	22	17	12
130	-	14	17	15	14	16	10	13	12	21	16	11

The resistance of the material to penetration of molten slags, metals and flue gases is determined by its level of porosity. The results of apparent porosity for the test samples are presented on Table 6. It could be deduced that the apparent porosity of the samples were lower when glass powder and bentonite additives were at a higher concentrations. Increasing the proportions of the additives reduces the apparent porosity of the samples because of the corresponding increase in the adhesive or binding forces between the material particles thereby reducing the number of voids within them. This observation was reported by (7) on the effect of High Aluminium Cement on selected foundry properties of ant-hill clay.

Table 5. Filtration rate of the ant-hill clay at different percentage of additives

Sample	Ant-hill clay (%)	Percentage of additives		Q (cm^3/Sec)
		Bentonite	Glass	
1	100	100	0	0.0046
2	100	90	10	0.0042
3	100	80	20	0.0045
4	100	70	30	0.0047
5	100	60	40	0.0044
6	100	50	50	0.0051
7	100	40	60	0.0048
8	100	30	70	0.0049
9	100	20	80	0.0037
10	100	10	90	0.0043
11	100	0	100	0.0050

Table 6**.** Apparent porosity of the ant-hill clay at different percentage of additives

Sample	Ant-hill clay (%)	Percentage of additives		Weight of dry samples (N)	Bulk density (g/cm^3)	Weight of soaked sample (N)	Apparent porosity (%)
		Bentonite	Glass				
1	100	100	0	3.48	17.8	3.51	0.00015
2	100	90	10	4.54	17.9	4.58	0.00016
3	100	80	20	4.22	17.8	4.27	0.00021
4	100	70	30	4.2	10.2	4.28	0.00019
5	100	60	40	3.74	17.5	3.78	0.00018
6	100	50	50	3.55	10.6	3.62	0.00021
7	100	40	60	3.38	17.6	3.42	0.00020
8	100	30	70	3.37	8.5	3.43	0.00015
9	100	20	80	3.19	9.5	3.25	0.00018
10	100	10	90	4.18	17.5	4.22	0.00017
11	100	0	100	5.18	17.7	5.25	0.00024

The bulk density of all the samples are appreciably high with the introduction of additives to the ant-hill clay body has indicated in Table 7. The test sample having 90% Bentonite and 10% glass powder produced the optimal value of 17.9 g/cm^3. This is quite high when compared to the bulk density value of 2.02 g/cm^3 obtained as the highest value for termite hill and asbestos-based additive as reported by [8].

Table 7. Bulk density of the ant-hill clay at different percentage of additives

Sample	Ant-hill clay (%)	Percentage of additives		Mass of samples (g)	Volume of sample (cm3)	Bulk density (g/cm^3)
		Bentonite	Glass			
1	100	100	0	280	15.7	17.8
2	100	90	10	274	15.3	17.9
3	100	80	20	285	16	17.8
4	100	70	30	307	30.1	10.2
5	100	60	40	250	14.3	17.5
6	100	50	50	305	28.9	10.6
7	100	40	60	260	14.8	17.6
8	100	30	70	350	41	8.5
9	100	20	80	252	14.5	9.5
10	100	10	90	288	16.5	17.5
11	100	0	100	275	15.5	17.7

Table 8. Permeability of the ant-hill clay at different percentage of additives

Sample	Ant-hill clay (%)	Percentage of additives		Permeability, K (Darcy)
		Bentonite	Glass	
1	100	100	0	0.0019
2	100	90	10	0.0017
3	100	80	20	0.0018
4	100	70	30	0.0019
5	100	60	40	0.0018
6	100	50	50	0.0021
7	100	40	60	0.0019
8	100	30	70	0.002
9	100	20	80	0.0015
10	100	10	90	0.0017
11	100	0	100	0.0020

The permeability test results are presented in Table 8. The permeability of the ant-hill became significantly low with the addition of glass powder and bentonite additives. The sample with 30% Bentonite and 70% glass powder gave a permeability of 0.0020 Darcy. This indicates that this sample provides a less porous additive-based refractory material associated with low permeability and which is also likely to exhibit good resistance to the penetration of molten slag and metal as well as flue gases. This given concentration of additives could be employed in the production of local refractory brick for furnace lining.

5. CONCLUSIONS

Some selected refractory properties of ant-hill clay have been evaluated based on the introduction of pulverised glass wastes and bentonite as additives in order to impart significant improvement on the ant-hill clay material for the purpose of producing a refractory clay brick for furnace lining. The compressive strength and the bulk density properties increase correspondingly based on the proportion of additives introduced, thereby providing optimal results of 666.7N/m^2 for the test sample consisting 100%Ant-hill/90%Glasspowder/10% Bentonite and 17.9 g/cm^3 for the sample having 90% Bentonite and 10% glass powder, respectively. The water-retention capacity, filtration rate, apparent porosity and permeability indicated a decreasing trend in value as additives are being introduced in varying proportions. However, this study is focused on determining the sample that best provides the optimal values of refractory properties suitable for making clay blocks for furnace lining.

The ant-hill clay with bentonite and glass powder additives is found to possess such favorable and desirable properties in terms of compressive strength, bulk density, apparent porosity and permeability. A significant outcome of this work is that it is possible to select percentage composition of additives with the ant-hill clay that give the desirable or compromised values of certain refractory properties that could be adopted in production of materials for lining local furnaces.

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