Effect of High Alumina Cement on Selected Foundry Properties of Ant-Hill Clay

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Abstract

The effect of high alumina cement (HAC) on some selected foundry properties of ant-hill clay was investigated. Pulverised clay, water and 5 to 40% HAC weight fractions were manually mixed, pressed and air dried at 110°C for twenty-four hours followed by firing in a kiln to 1100°C. For each property, four samples were prepared, tested and the average value reported. The results showed that the values of the investigated properties generally increased up to 15% HAC after which no significant improvement was observed. At an optimum 15% HAC, compressive strength increased from 4933.50 N/mm^2 to 6457.25 N/mm^2. In addition, refractoriness increased from 1450°C to 1600°C at this optimum weight percent. Apparent porosity was also observed to be improved in the tested samples. It was concluded that for a refractoriness value of 1600°C, the optimum mix of 15% HAC would be suitable for metallurgical furnace linings.

Keywords

High alumina cement; Ant-hill clay; Compressive strength; Refractoriness; Apparent porosity; Linear shrinkage.

Introduction

Refractories are the main components utilised in the metallurgical industry for furnace construction. They are used in the lining of melting, smelting, holding and re-heating furnaces. A refractory is any material that can withstand the action of abrasive or corrosive solids, liquids or gases at high temperatures [1]. Other general requirements of a refractory material are ability to withstand sudden changes in temperatures, conservation of heat and low coefficient of thermal expansion [1,2].

Researchers in recent years, especially in the developing countries, have focused on the utilisation of natural clays for refractory production. These researches can have great impact on the industrialisation of a nation and save foreign exchange. Many researchers have worked on refractory fireclays which abound in Nigeria. However, the refractory properties of natural clays need to be upgraded to make them suitable for use in metallurgical furnaces. Graphite and asbestos additions have been used in enhancing the refractoriness of natural clay deposits such as termite and ant-hills [3]. Reference to the use of silicon carbide [4] and silica, mica and bentonite [5,6] on the refractory properties of some other local deposits have also been reported.

Whereas some types of clay, such as kaolinite clay [7], are naturally plastic, and therefore may not require any type of binder, silicate and alumina binders [8] have been used both as binders and for enhancing the working temperature of clay refractories. High alumina cements are generally regarded as high temperature refractory concretes [8].

The aim of the research was to investigate the effect of high alumina cement, HAC, on the refractory properties of ant-hill clay deposit.

Material and Method

The materials that were used for this research work included naturally occurring ant-hill clay obtained from one of the numerous mounds that abound in the teak plantation of the Federal University of Technology, Akure (FUTA), Nigeria and commercial grade of durax, a high alumina cement (HAC) from Vesuvius, Incorporation, USA.

A Denver laboratory pulveriser was used in pulverising the clay samples while a ball mill was used in the grinding process. A Testometric Universal Testing Machine equipped with a computer and printer was used in carrying out the mechanical tests. A laboratory oven and kiln were used to dry and sinter the samples respectively. Other equipment used included a sieve shaker with a set of sieves and a laboratory weighing balance.

Experimental Procedure

Chemical Analysis

The lumps from the ant-hill were crushed and ground. Chemical analysis of the ant-hill clay, as indicated in Table 1, was carried out using atomic absorption spectroscopy (AAS) and Ignition Loss Method. The result showed that that the sample contained a high percentage of silica. The mound/hill can, therefore, be classified under siliceous fireclay [9]. This result further showed that the clay belongs to the fireclay accepted standard [10] and falls within the range of semi-plastic fireclays [11].

Table 1. Compositional analysis of ant-hill clay

Constituent	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO	Na_2O	K_2O	L.O.I	**TOTAL**
Percentage composition	58.83	22.69	2.42	0.72	0.01	0.84	0.06	2.10	12.33	**100%**

The high alumina cement, HAC, is of DURAX™ C1700 brand from Vesuvius Inc. USA, as stated in the product information sheet. It is a high alumina conventional castable. It has a service temperature of about 1700°C (3100°F). Its alumina content (Al_2O_3) is 85 %, silica (SiO_2) is 5 %, while iron oxide (Fe_2O_3) is 1 %.

Sieving and Sizing

Classification to particle sizes ranges of 2.0-1.5 mm, -1.5–1.0 mm and -1.0–750 μm was done with a sieve shaker and a set of sieves. The sized clay was mixed in the ratio 45:25:30 respectively to obtain fine and coarse particles that can be combined for enhanced pore closing during sintering and calcinations processes.

Mixing

Various samples were prepared. Pre-determined masses of clay and cement were weighed using a laboratory weighing balance and manually mixed together for each of the batches. 10 cm^3 of water was added to make the mixture plastic and mouldable. The total matrix utilised for each batch sample weighed 400 g. The percentage by weight of HAC and clay are indicated in Table 2. Since the cement was used both as a binder and an additive, its percentage constituent in the matrix was designed not to exceed 40% by weight of the total matrix. Sample A was 100% clay while Sample J was 100% HAC. The average density of the samples was found to be 20 g/cm^3.

Table 2. Percentage by weight of HAC in the matrix

Samples	A	B	C	D	E	F	G	H	I	J
% by weight of *HAC*	0	5	10	15	20	25	30	35	40	100

After a homogenous mixture of clay, HAC and water was obtained, the plastic paste was then rammed into a cylindrical shaped steel casing to produce disc samples, for the selected tests. Four samples were produced for each of the selected refractory tests. The average obtained for each test was reported.

Drying and Firing

The disc samples were left to dry in the open laboratory atmosphere for 24 hours to remove moisture from them and thus increase their green strength, making them safe for further handling[2]. The dried specimens were then transferred into the oven for drying at 110°C for a period of 8 hours. The samples were allowed to cool over night in the oven before firing was done at 1100°C for five hours.

Mechanical and Refractory Testing

On cooling, compressive tests, refractoriness, porosity, and linear shrinkage were carried out on the fired test specimens.

Results and Discussion

Effect of Varied Weight Percent of HAC on the Compressive Strength of the Specimens

The compressive strength of the disc samples was evaluated as stress at peak. Figure 1 below depicts this. It was observed that Sample J, 100% HAC, had the highest strength of 7937.50 N/mm^2 whereas the lowest value of 4176.25 N/mm^2 was recorded for Sample C which had 10% HAC. Sample A which was 100% clay had a strength value of 4933.50

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N/mm^2, ranking as the second lowest strength value. There were improvements in strength levels as the HAC content increased from 5 to 15%, except for Sample C, which had the lowest value. This could be attributed to the high cohesive force of attraction between the clay and the cement particles and consequently, the high frictional forces that were generated between the particles during loading. The strength level slightly peaked at Sample D (6457.25 N/mm^2) for the samples with HAC addition.

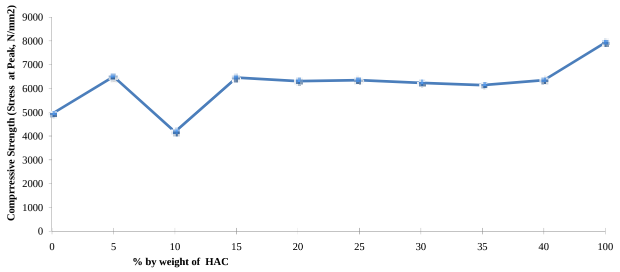

Figure 1. *Graph of compressive strength of samples*

Effect of Varied Weight Percent of HAC on the Apparent Porosity of the Test Samples

The graphical representation of the result of the percentage apparent porosity test is depicted in figure 2. This parameter is a micro structural variable that must be controlled to produce a suitable refractory [9]. Porosity, grain size and grain orientation are the micro structural parameters of significant importance to the strength of inorganic materials [12].

Clay composition, size and shapes of particles, ramming pressure, and the reaction occurring on firing are some of the factors that affect the porosity of refractories [13]. The porosity measures the ease with which liquid and gas seep through the refractory material. The highest porosity of 22.70% was recorded for Sample A, which was 100% clay. Though it had very fine grains which would have tightly closed up during pressing (manual ramming), the value of its L.O.I (Loss on Ignition) indicated that some organic matters were burnt off during firing, and hence, its high value of porosity. The particles of the HAC on the other hand, though quite large in comparison to the fine clay particles, manual ramming may not have broken them up to ensure a good pore closing as would be expected for fine particles.

Nonetheless, the lowest value of porosity of 16.87% was recorded for sample J of 100% HAC being totally devoid of organic matter as indicated in the product information fact sheet.

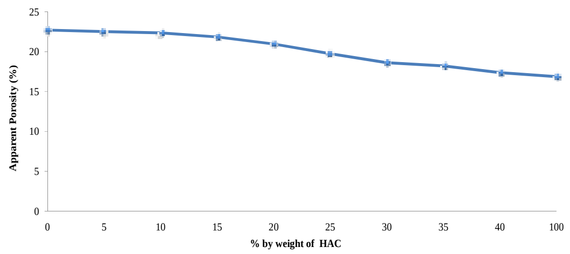

Figure 2. *Plot of apparent porosity of samples*

Porous refractories have poor heat conductivity, high permeability, low strength, and less sensitivity to fluctuations in temperatures [2], which is consistent with the value obtained for Sample A from the recorded results of the experimental data. A comparison of the strength and porosity of the tested specimens, as depicted in Figure 3 below, shows that strength increases with decrease in porosity. The presence of pores in clay affects the strength by reducing the cross-sectional area exposed to an applied load. They also act as stress raiser or concentrator especially in brittle clays [14]. It was also stated that as resistance to corrosive attack increases with porosity reduction, thermal insulation characteristics and resistance to thermal shock are, however, diminished [13]. Porous refractories have pores that are air-filled which serve as insulator and hence the heat conductivity of a refractory material decreases with increasing porosity. Porous refractories, therefore, act as good insulators [2]. The porosity of Sample A makes it a candidate material for insulating refractory bricks.

However, a low apparent porosity is desirable for a refractory in contact with molten charge and slag since it would prevent easy penetration of the refractory size [1,6]. This assertion makes Samples J, I and H suitable candidates (in descending order of porosity) for melting furnace refractories, all other factors held constant. Nonetheless, Sample D, with its attendant high strength and relatively low porosity may be a better replacement when cost is also considered (15% by weight of HAC).

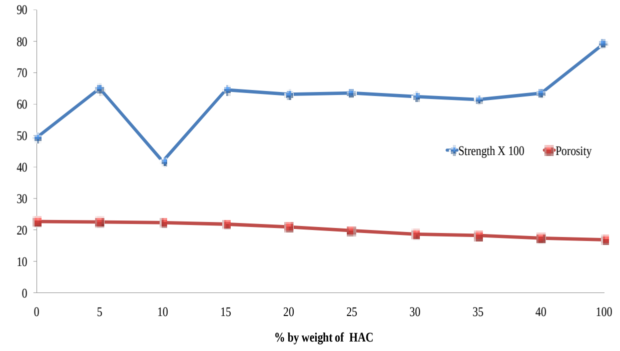

Figure 3. *Plot comparing compressive strength with apparent porosity of samples*

Effect of Varied Weight Percent of HAC on the Refractoriness and Percentage Linear Shrinkage of the Specimens

Figure 4 depicts the values obtained from the refractoriness test. All the samples were observed to have refractoriness not less than 1400°C. This is comparable to the result reported by Olasupo and Borode in [5,6]. No softening or loss in structural integrity was observed at this temperature. This is a strong pointer to the high quality of the ant hill clay utilised for this research work. An average of 1400°C has been reported as the refractoriness of termite hill clay [5]. Sample J, 100% HAC had a refractoriness of 1700°C, the highest for the whole lot. Samples F and G, however, had the lowest value of refractoriness, which was 1400°C. Again, as observed for compressive strength values, increment in HAC addition above 15% does not have a significant effect on the refractoriness of the samples, meaning that it was the limiting value. Refractoriness from Sample A (100% clay) increased with increasing content of HAC, peaking at Sample D with a value of 1600°C before a decline in this property began to manifest. Samples B and C had the same value of refractoriness of 1550°C. Increasing the HAC for Samples F through I had no effect on the refractoriness of the samples. In fact, a decline (from 1500 to 1400°C) was observed. The 100% clay of Sample A had a higher value of refractoriness of 1450°C than any of Samples F through I. This reduction in refractoriness could have been due to the presence of impurities such as gravel, stones and other organic matters that might have remained in the blend, after sieving.

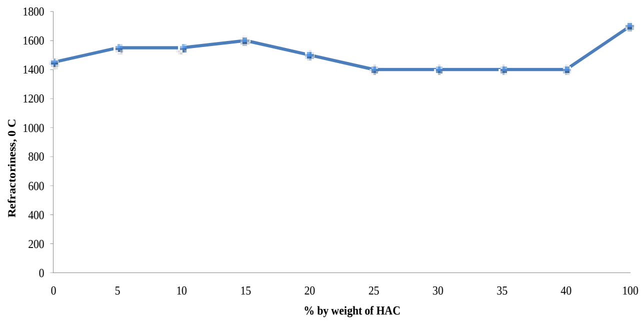

Figure 4. *Graph of refractoriness of the test samples*

On the other hand, looking at figure 5, Sample A had the highest value of 4% linear shrinkage for the whole samples tested. No significant change in size was observed for Samples J and D through I. Sample A which had a linear shrinkage of 4% is also in tandem with the results reported in fireclay accepted standard [12]. Low firing shrinkage always gives an indication of uniform and firing efficiency [10].

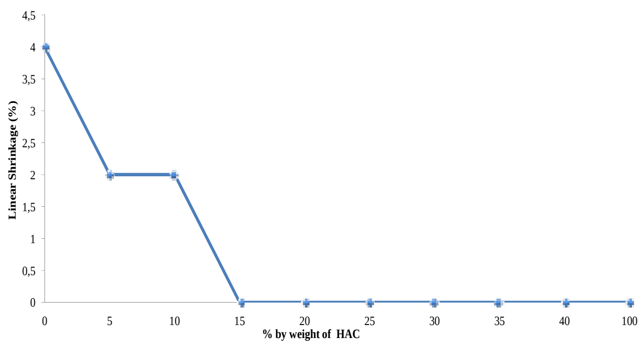

Figure 5. *Graph of linear shrinkage of test samples*

Conclusions

The results of this research work showed that the compressive strength and other properties such as refractoriness, porosity, and linear shrinkage of ant-hill clay were effectively improved upon by the addition of HAC. This additive increased the refractoriness of ant-hill clay from 1450°C to 1600°C at an optimum 15% weight fraction. The compressive strength of the clay was also enhanced with inclusion of the cement in the matrix. At 15% HAC addition, an approximate 31% increment in compressive strength was recorded. It was found out that the compressive strength increased from 4933.50 N/mm^2 to 6457.25 N/mm^2. However, apparent porosity and linear shrinkage of the clay sample were reduced by the cement addition. This observation, nonetheless, is not detrimental as too porous refractory products are susceptible to slag attack and permeability from gases and molten metal. At the optimum 15% HAC addition, the refractory product may be recommended for use in sintering furnaces, re-heating furnaces operating below 1500°C, and for non-ferrous casting furnaces.

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