THE EFFECTS OF SILICON CARBIDE ON SOME REFRACTORY PROPERTIES OF BAUCHI CLAY

By

S. B. HASSAN
Department of Metallurgical Engineering
Ahmadu Bello University, Zaria.
e-mail: hassbolaji@yahoo.com

ABSTRACT

Some refractory properties of Bauchi clay, found in abundant in Alkaleri area of Bauchi State, Nigeria blended with silicon carbide, for the production of refractory bricks for furnace lining has been Investigated. 5 - 25% silicon carbide was used as blend to enhance some refractory properties such as porosity and thermal shock resistance of the clay. Refractory properties measured included: Linear shrinkage, apparent porosity, bulk density, thermal shock resistance and cold crushing strength. Linear shrinkage and apparent porosity of the bricks made from the blend decreased with the percentage of silicon carbide added. These properties decreased from 5.66 to 2.49% and from 33.02 to 16.31% at 25% silicon carbide level respectively. The cold crushing strength and thermal shock resistance of the bricks increased as the percentage of silicon carbide added increased.

1.0 INTRODUCTION

With the development of iron and steel industry in Nigeria, there has been a great increase in the use of refractory materials. For instance, the Ajaokuta steel complex on completion will require about 36,000 tones of refractory bricks worth over Sixty million Naira just for furnace lining purposes only. In fact more than 80% of the refractory bricks to be required at Ajaokuta will be fireclays (Hassan and Adewara, 1993). The development of our local materials for the production of refractories is justified by the need to meet the technological requirements of the country, and to conserve the much-needed foreign exchange. Silicon carbide refractories are known as the "First-Quality" refractories and contain at least 85% silicon carbide (Chesti, 1986). Silicon carbide has won an important place in the ceramic, metalworking and process industries due to its excellent combination of properties. The basic material for silicon carbide refractory bricks is silicon carbide (SiC), which is electrically fused from quartz and carbon (Senta, 1991).

Earlier works on various Nigerian refractory clays' deposits have shown many of them to be rather high in silica content and low in alumina (Ahmed, 1986; Aniyi, 1986 and Hassan, 1990).

Bauchi clay was found to be unsatisfactory in some refractory properties (Hassan, 1990). The thermal spalling resistance was found to be very low. The apparent porosity values were found to be 33% and higher than the normal range for dense refractory bricks. The rising temperature characteristics showed that the clay could be used in furnace applications operating at temperatures up to 1500°C (Hassan, 2000).

The evaluation of some refractory properties of Bauchi clay blended with silicon carbide is the objective of this present study.

2.0 EXPERIMENTAL PROCEDURE

2.1 MATERIALS

The experimental materials used for the investigation was Bauchi clay obtained from Alkaleri village of Bauchi State which had been procured by the Department of Metallurgical Engineering, Ahmadu Bello University, Zaria. The Silicon carbide was purchased in form of grounded aggregate of 120μm size from a chemical store in Kaduna, Nigeria. A set of four sieves of sizes 1000μm, 710μm, 355μm, 150μm and the pan was used to obtain the three classes of size aggregates used. Fabricated moulding boxes of different dimensions according to refractory properties test requirement were used for the moulding of the test brick samples. An electric muffle furnace with a maximum operating temperature of 1600°C was used for the firing of the brick samples.

2.2 METHODS

The experiments were all carried out in the Departmental laboratory. The initial processing of clays began by crushing the raw clays as mined, soaking it in water for two or three days and then dried in the sun. This treatment was necessary to remove principally alkalis and some dead organic matters. The presence of alkalis, containing sodium and potassium, is known to retard mullite formation and hence lowers the refractoriness and strength. The dried clay was then grounded into powder and sieved to pass through a set of four sieves of sizes 1000μm, 710μm, 355μm, and 150μm. From these, three classes of aggregates were obtained, the coarse aggregates that were retained on the 710μm sieve, the medium and fine aggregates were those retained on the 355μm, and 150μm sieves respectively. Test samples were made by mixing 5 - 25% silicon carbide aggregates with Bauchi clay aggregate with 22 percent water level, and then pressed to shape by the application of $10 kg/cm^2$ pressure. The water content of 16% by weight was found sufficient for moulding. The samples were dried, first in the open air for 24 hours followed by oven drying for 12 hours at 110°C before firing. Firing was done in an electric muffle furnace at a heating rate of 7°C/minute. The firing procedures were successively carried out as follows;

(a) Heating at a slow rate at 7°C/minute to a temperature 350°C and allowed to soak for 6 hours.

(b) Heating for 4 hours at a temperature 650°C, for 3 hours at 950°C, and then for 8 hours at

1300°C,

(c) Cooling in furnace to room temperature.

The fired refractory bricks produced were tested for linear shrinkage, apparent porosity, bulk density, cold crushing strength, and thermal shock resistance which are the common refractory properties (Adeyemi, 2001) and due to the available experimental equipment in the Departmental laboratory.

2.2.1 Measurement of Linear Shrinkage

Green bricks were pressed in a box of size 42mm x 40mm x 40mm. The shrinkage properties of the pressed bricks were determined by measuring the green dimension of the bricks, using a vernier caliper. These were then compared with the fired dimensions. The linear shrinkage was calculated as a percentage of the original green dimensions (i.e. $\Delta L/L$). The result produced is shown in Table1.

Where ΔL is the change in length of the fired brick

L is the original length of green brick

2.2.2. Determination of Apparent Porosity and Bulk Density

For each of the blended samples, four test bricks each of 46mm x 42mm size after firing were tested. The dry weight (W_1) of each specimen was measured, after which the specimen was transferred into and suspended in a vessel of boiling water for 20 minutes. At this time, the boiling was discontinued and the hot water was replaced by cold water. After 30 minutes in cold water the weight (W_2) was measured. The soaked specimen was then weighed in air (W_3). The apparent porosity of the brick were calculated using the following relations (Thring, 1962):

$$P_a = \frac{W_3 - W_1}{W_3 - W2} \times 100\,\%$$

Where P_a is apparent porosity

W_1 - weight of dry sample

W_2 - weight of sample suspended in cold water

W_3 - weight of soaked sample suspended in air

The bulk density B_D was determined from the relationship below:

$$B_D = \frac{W_1}{W_3 - W2}$$

The results are summarized in Table 2.

2.2.3 Determination of Cold crushing Strength

Standard bricks measuring 76mm cube were tested for strength under a universal strength-testing machine. The strength values of the bricks both in the direction of forming and direction normal to the direction of forming were recorded. Two samples per blend were tested for each of the directions. The results are shown in Table 3.

2.2.4 Determination of Thermal Shock Resistance

A standard brick measuring 50.8mm square base by 76.2mm high was put in the furnace, which was maintained at 1300°C for 30 minutes. The brick was brought out to cool in air for 10 minutes. The brick was tested for failure using a standard rig. If fracture failed to occur, then the brick was then put back into the furnace and reheated for a period of 10 minutes. This cycle of heating, cooling and testing was then repeated, until fracture occurred. The number of complete cycles required to produce fracture in each specimen was noted. The results are shown in Table 4.

3.0 RESULTS AND DISCUSSION

3.1 RESULTS

The results of surface appearance, linear shrinkage, apparent porosity, bulk density, cold crushing strength and thermal shock resistance of the refractory bricks produced from Bauchi clay blended with silicon carbide are tabulated in Tables 1 – 4 (see Appendix). The graphs of variation of the refractory properties with silicon carbide addition are shown in Figures 1 – 5.

3.2 DISCUSSION

3.2.1 Surface Appearance of the Brick

There was a slight colour change in the bricks containing 5% silicon carbide after firing. For silicon carbide level of between 10 - 25%, no colour changes occurred after firing (see Table 1).

3.2.2 Linear Shrinkage

The curve of decreasing effects of silicon carbide addition on the linear shrinkage is shown in Figure 1. From the graph, the linear shrinkage of the bricks produced decreased gradually at first and from 15 percent silicon carbide addition and above, the decrease was rapid. This is due to the presence of high proportion of silicon carbide couple with its low shrinkage properties. An average shrinkage value of 5.66% was obtained for bricks produced from 100 percent Bauchi clay while comparatively lower shrinkage value of between 5.23 to 2.49% were obtained for the bricks made from 5 - 25% silicon carbide additions respectively (see Table 1). These values are below the range 7-10% value normal for kaolin (Thring, 1962). The firing shrinkage is calculated from the difference between the total and drying shrinkage. The firing shrinkage is particularly significant since it gives an indication of the efficiency of firing. The total shrinkage decreases with percentage silicon carbide additions from 5.66 - 2.49% for 100% Bauchi clay to 25% SiC addition (Figure 1). These suggest that not much vitrification had taken place for these grades of bricks.

3.2.3 Apparent Porosity and Bulk Density

The apparent porosity for bricks made from 100% Bauchi clay is found to be higher than the normal range of between 20 and 30% for fired bricks (Table 2). However, bricks made from silicon carbide additions to Bauchi clay resulted in decrease porosity values ranging from 29.79 to 16.31% for 5 - 25% silicon carbide additions respectively (see Figure 2). There seems to be no direct relationship between firing shrinkage and porosity of 16.31%. The high firing shrinkage would have resulted in the closure of internal pores and hence leading to reduced porosity. The bulk density values of the bricks made from 5 - 25% SiC addition to Bauchi clay are found to be within the acceptable range of between 1.7 - 2.1 g/cm^3 for dense fired bricks (Figure 3).

3.2.4 Cold Crushing Strength

All the refractory bricks produced from Bauchi clay blended with silicon carbide have good and moderate cold crushing strength values in the direction of pressing. These are higher than the recommended minimum of 15,000 KN/m^2 for dense fired bricks (see Table 3). The cold crushing strength increases with silicon carbide additions with a value of 39,332KN/m^2 at 25% addition (Figure 4).

The bricks produced from the blended Bauchi clay have good cold crushing strength values due to the high bonding between the silicon carbide particles and clay particles. Similar results are obtained for cold crushing strength values for the blends in the direction normal to forming (Table 3). The values are much higher than the recommended minimum of 5,000 KN/m^2.

3.2.5 Thermal Shock Resistance

Figure 4 shows the characteristic curves of thermal shock resistance of the bricks made from the blend. These curves show a rising characteristic of the thermal shock resistance of the bricks both at 1100 and 1300°C. The bricks made from the blends are found to fail before the recommended minimum of 30 cycles in respect of test carried out at 1100°C (see Table 4). The bricks from 100% Bauchi clay have extremely poor thermal shock resistance value of 8 cycles, while a maximum value of 15 cycles were obtained at 25% silicon carbide additions at this temperature.

The spalling tests done at 1300^{0}C indicate an acceptable thermal shock resistance for all the bricks containing 5 – 25% SiC (see Table 4). This is probably due to soft phases being formed at 1300^{0}C, which on cooling inhibit brittle failure in bricks. The improvements in spalling properties for the bricks made from the blends are not unconnected with the sintering characteristics of the silicon carbide as compared to Bauchi clay.

4.0 CONCLUSION

From the results of this study, it can be concluded that the addition of 5 - 25% silicon carbide to Bauchi clay gave an improvement in the linear shrinkage, apparent porosity, cold crushing strength and thermal shock resistance properties of Bauchi clay. The values of these physical properties compare very favourably with those for fireclay refractory bricks. It has been established in this investigation that the blending of Bauchi clay with about 15 percent silicon carbide will eliminate the problem of high porosity and low thermal shock resistance characteristics of this clay. Hence good quality refractory bricks capable of withstanding operating temperature of at least 1700°C in furnace lining could be produced.

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APPENDIX:

Table 1: Surface Appearance and Linear Shrinkage of the Bricks

Silicon Carbide (%)	Appearance of Fire Bricks at 1200°C				Linear Shrinkage of Fire Bricks		
	Drying 110°C for 24 hours		Fired at 1200°C		Drying Shrinkage (%) (a)	Firing Shrinkage (%) (b)	Total Shrinkage (%) (a) + (b)
	Colour	Crack Formation	Colour	Crack Formation			
0	White	No crack	White	Crack	5.40	0.26	5.66
5	Light Cream	No crack	Dark cream	Slight crack	5.01	0.22	5.23
10	Dark Cream	No crack	Dark cream	Slight crack	4.79	0.22	5.01
15	Ash Colour	No crack	Ash colour	No crack	4.26	0.19	4.45
20	Ash Colour	No crack	Ash colour	No crack	3.09	0.16	3.25
25	Ash Colour	No crack	Ash colour	No crack	2.34	0.15	2.49

Table 2: Apparent Porosity and Bulk Density of the Brick Samples

Silicon Carbide	W_1	W_2	W_3	Average Porosity (%)	Average Bulk Density (g/cm^3)
(%)	(g)	(g)	(g)	$\frac{W_3 - W_1}{W_3 - W_2} \times 100$	$\frac{W_1}{W_3 - W_2}$
0	110.00	56.92	136.16	33.02	1.39
5	115.52	64.18	137.30	29.79	1.58
10	119.65	65.18	139.41	26.62	1.61
15	125.41	66.19	142.34	22.24	1.65
20	130.04	67.97	146.00	20.46	1.67
25	135.00	68.27	148.00	16.31	1.69

Table 3: Cold Crushing Strength of the Brick Samples

Silicon Carbide Addition	Average Cold Crushing Strength (KN/m^2)	
(%)	Direction of Forming	Direction normal to Forming
0	19,210	7,100
5	24,672	11,023
10	29,904	13,530
15	31,220	15,769
20	33,448	19,412
25	39,332	21,477

Table 4: Thermal Shock Resistance of the Brick Sample

Silicon Carbide Addition	Spalling Tests at 1100°C		Spalling Tests at 1300°C	
(%)	No. of Cycles	Remark*	No. of Cycles	Remark*
0	8	Poor	13	Poor
5	10	Poor	15	Acceptable
10	11	Poor	17	Acceptable
15	11	Poor	20	Fair
20	13	Poor	24	Fair
25	15	Acceptable	27	Fair

* Excellent (> 30), Good (25 - 30), Fair (20 - 25), Acceptable (15 - 20), Poor (< 15).

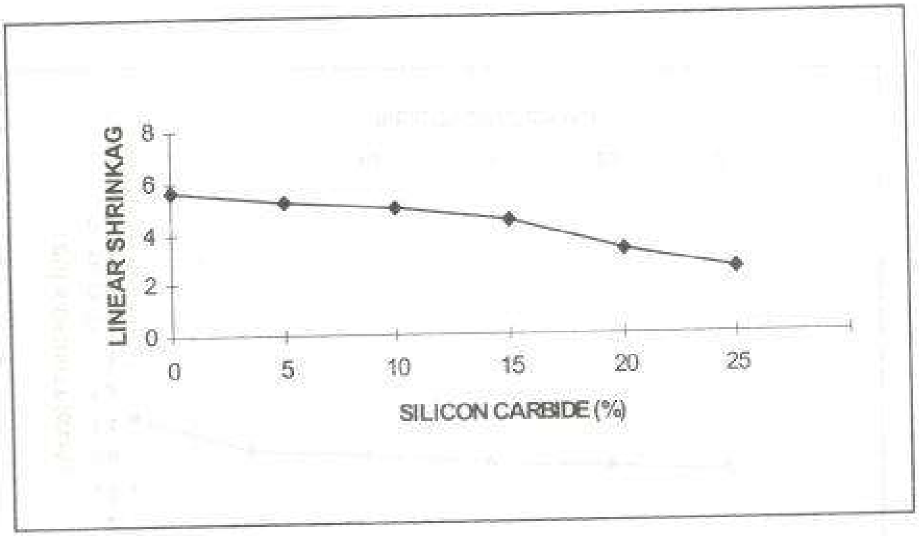

Figure 1: Effect of Silicon Carbide addition on Linear Shrinkage of the Brick

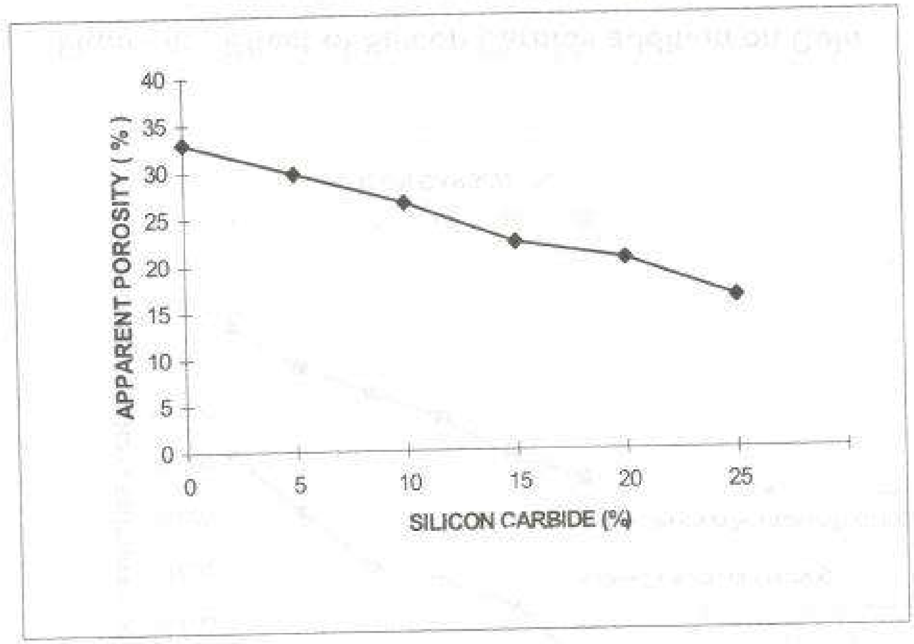

Figure 2: Effect of Silicon Carbide addition on of Apparent Porosity of the Brick

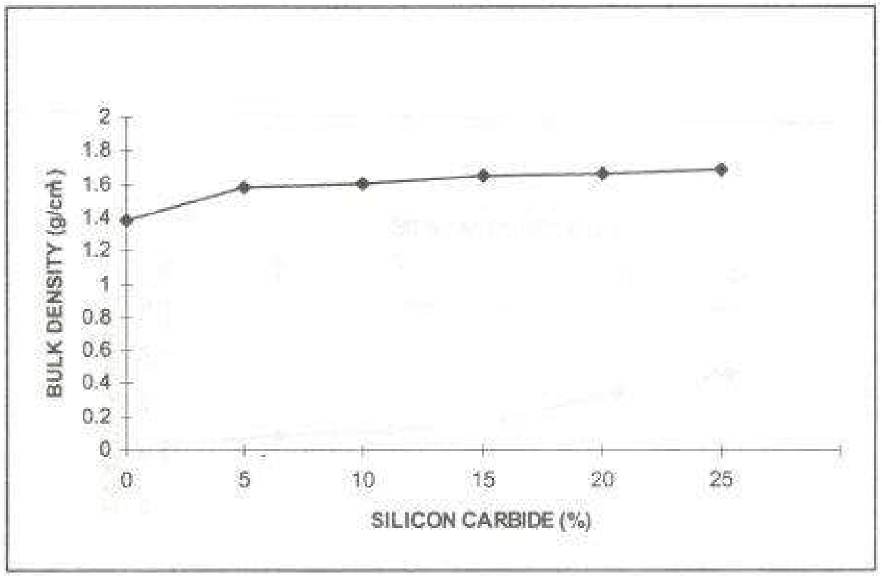

Figure 3: Effect of Silicon Carbide addition on Bulk Density of the Brick

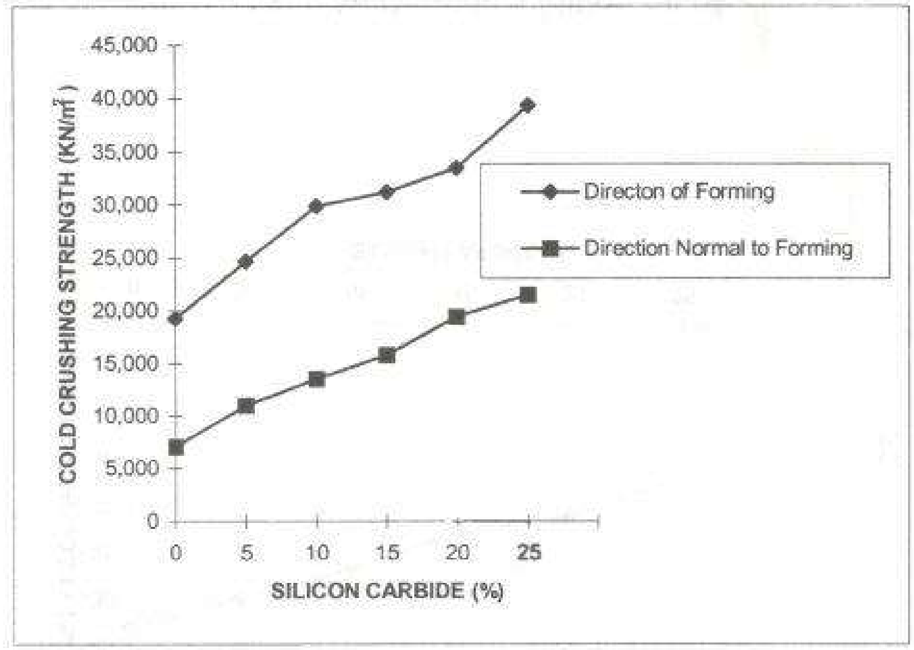

Figure 4: Effect of Silicon Carbide addition on Cold Crushing Strength of the Brick

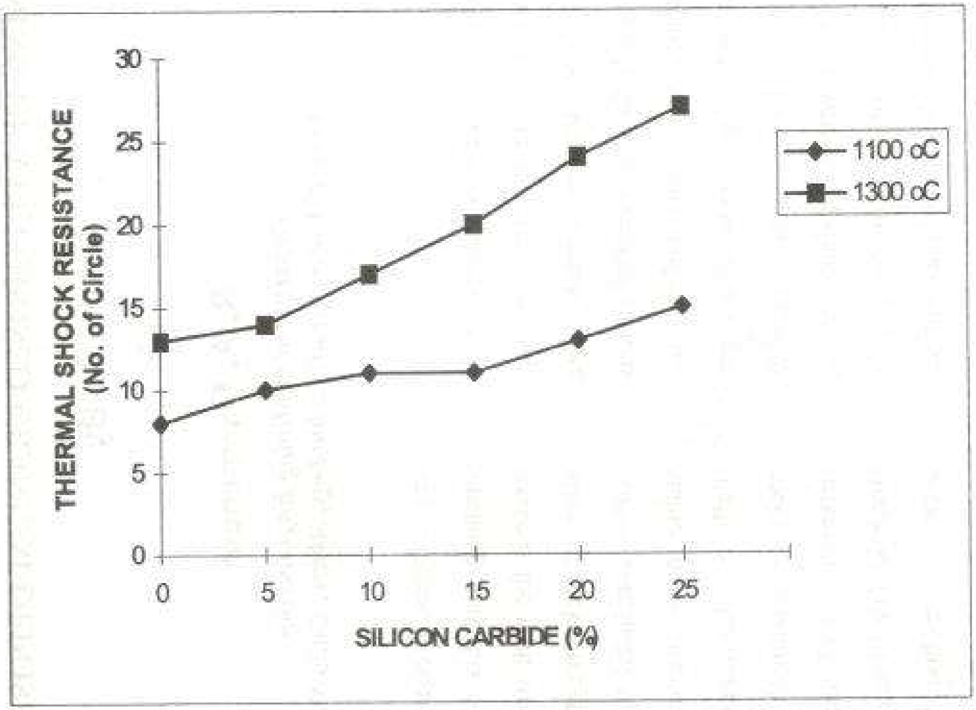

Figure 5: Effect of Silicon Carbide addition on Thermal Shock Resistance of the Brick