Effect of lime on some physical properties of mud as an alternative refractory material for lining of furnaces

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Abstract

In ceramic industries, lime or calcium oxide (CaO) has been used successfully to improve the permeability of materials made from clay. This paper presents the outcome of research into the possible use of mud mixed with lime to improve the quality of mud bricks for use in lining of furnaces in the foundry. Results of the tests show that mud generally consist mainly of very fine clay and silt particles sizes less than 300 μm. It was also found that the addition of lime in mud improves the permeability with an average conductivity of 1.15 mm/s. The addition of lime also reduces the resistance of the mud to thermal resistance as the samples indicated cracks at high temperatures. The compressive strength and setting time of the mud- lime brick was found to increase progressively. The addition of lime to mud can therefore be recommended for low temperature furnace lining.

Keywords

Lime; Calcium oxide; Furnace; Clay; Mud; Permeability; Thermal resistance; Refractory; Grain size distribution

Introduction

Lime or calcium oxide (CaO) is a product of de-carbonizing of calcium carbonate ($CaCO_3$). It is a white crystalline solid with a melting point of 2,572°C. It is manufactured by heating limestone, coral, sea shells, or chalk to drive off carbon dioxide. The abundance of limestone in the earth's crust and the ease of its transformation to calcium oxide explain why the lime is one of the oldest products of chemistry [1]. Lime has many properties that make it quite valuable. The cementing action of lime is produced by carbonation. Calcium hydroxide combines with the carbon dioxide from the atmosphere to form calcium carbonate which has cementing properties. The chemical reaction is as follows:

$$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O$$

Mud is a dark brown earth composing mainly of organic materials, sand, silt and clay with high content of the latter. Clay minerals which are the major component of mud are an important group of minerals because they are among the most common products of chemical weathering, and thus are the main constituents of the fine-grained sedimentary rocks called mud rocks (including mudstones, clay stones, and shales).

Clay deposits in Nigeria as refractory material have been researched into in order to determine their suitability for foundry application [2]. Chukwudi [3] carried out the characterization and evaluation of the refractory properties of Nsu clay deposit in Imo state, while Kefas *et al* [4] characterized the Mayo-Belwa clay in Adamawa state.

Clay is a decomposition of the mineral feldspar and is more or less impure hydrated aluminium Silicate. The refractory properties of natural clays need to be upgraded to make them suitable for use in metallurgical furnaces [5]. Graphite and asbestos additions have been used in enhancing the refractoriness of natural clay deposits such as termite and ant-hills [6]. Reference to the use of silicon carbide [7] and silica, mica and bentonite [8, 9] on the refractory properties of some other local deposits have also been reported.

A furnace is an apparatus in which heat is liberated and transferred directly to solid or fluid charge mass, for the purpose of effecting a physical or chemical change, through cycle involving temperature in excess of 400°C. There exist various classifications of furnaces based on the purpose and energy source [10]. In Nigeria small scale foundry process has been limitedly practiced owing to the fact that lining materials used in furnace constructions have been inadequate. Most small scale foundry outlets in Nigeria make use of cold mud as

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refractory in building their furnaces. Cold mud usually takes time to cure initially and when it comes in contact with water it takes so much time to dry. Mud in its characteristic nature attains proper strength and relative impermeability only when it is cured at a temperature between 940°C and 1200°C so that vitrification can take place which at most times is unattainable using local practices. Such weak furnace lining usually gives way within the shortest possible time. Alternatively, foundries looking for long lasting furnace resorts to the use of cement concrete as lining materials, but in this case, poor thermal properties are exhibited. It is therefore necessary in Nigeria to develop a local technique of construction of furnaces given the fact that foundry engineering is a very vital aspect of industrial production as it serves as a major contributor to mechanical production processes.

This study was aimed at verifying the effect of lime on the compressive strength, thermal resistance and permeability of mud bricks to ascertain if this can be used as an alternative refractory material for furnace lining. Furnace lining [11] is a protective and insulating layer of heat resistant material attached to the inside of the shell, hearth, and tap holes of a furnace. This layer serves to protect the furnace parts from the extreme heat developed during melting and related operations. It also prevents excessive heat loss from the external furnace surfaces making the process more efficient. Refractory [5] are materials used in metallurgical and foundry industries for the construction of furnaces, kilns, ovens, crucibles and retorts, on account of their high resistance to heat.

The investigation was limited to measuring some physical properties: grain size distribution, compressive strength, thermal conductivity and permeability of the bricks made from mud mixed with lime at various percentage levels, to ascertain the effect of lime on these physical properties of the mud.

Material and method

Samples of mud from four locations namely:- Bosso area of Bosso Local Government Area in Niger State; Umunede area of Ika North East Local Government in Delta State; Afobaje area of Songo local Government Area in Ogun State and Afa Udi Local Government of Enugu state all in Nigeria were collected and used for the investigation. The following experiments to determine the physical properties of the collected samples were carried out as follows:

1. Grain size. The following apparatus were used to determine the grain sizes of the mud sample: British standard test sieve sizes; weighing balance; sieve brush; a light mortal with pestle; a scoop; a mechanical sieve shaker, and mud samples. Samples weighing 800g from each of the locations were grinded using pestle and mortar into fine particles of various proportions. 600g of the grinded the samples was placed on the mechanical sieve shaker. This was shaken for ten minutes. The amount of grains retained on each sieve size was collected, weighed and recorded [12].
2. Brick production. Cylindrical bricks measuring 50mm diameter by 70mm height were produced by mixing 60g of the mud with calcium oxide (lime) at the ratio of: 0%, 20%, 30%, 40% and 50% by volume for each sample. Water was added to the mud-lime mixture and mixed using motorized mixer. The cylindrical samples were produced by hand moulding. Curing and drying of the samples was achieved by covering with nylon sheet and then allowed to dry naturally at a temperature of 35°C for 5 days [5].
3. Compression test. The bricks were placed in a compression testing machine and subjected to compression. The maximum force required to fail each brick was recorded [2].
4. Thermal resistance test. Samples produced for thermal test were subjected to thermal stresses at temperatures of 200°C, 300°C, 400°C, and 500°C. Their increase in diameter was recorded using a vernier caliper.
5. Permeability test. The permeability test was carried out using the permeability testing machine. The corresponding permeability data was read from the scale and recorded.

Results and discussions

The results shown on Tables 1, 2, 3 & 4 represent the results of the sieve analysis carried out on the four samples from the study areas of: 1. Umunede Area of Ika North East Local Government in Delta State; 2. Afobaje Area of Songo local Government Area in Ogun State; 3. Afa Udi Local Government of Enugu state, and 4. Bosso Area of Bosso Local Government in Niger State.

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Table 1. Sieve analysis for sample 1(Delta state mud)

Sieve size	Weight of sieve and sample	Weight of sieve	Weight of sample retained	Weight of passing	Percentage (%) retained	Cumulative retention
1.18mm	367.21	363.6	3.61	510.29	0.703	3.61
600μm	327.70	317.5	10.20	500.09	1.99	13.81
300μm	316.90	290.6	26.30	473.79	5.12	40.11
150μm	362.40	274.9	1.39	472.4	0.27	41.50
75μm	513.70	261.7	252.00	220.4	49.09	93.50
Pan	654.6	434.2	220.40	0	42.92	513.90
Total			513.90			

Table 2. Sieve analysis for sample 2 (Ogun state mud)

Sieve size	Weight of sieve and sample	Weight of sieve	Weight of sample retained	Weight of passing	Percentage (%) retained	Cumulative retention
2.35mm	396.80	387.5	9.30	590.10	1.55	9.30
1.18mm	382.90	363.6	19.30	570.80	3.21	28.6
600μm	354.50	317.5	37.00	533.80	6.17	65.6
300μm	467.20	290.6	176.60	357.20	29.46	242.2
150μm	533.40	274.9	258.50	98.70	43.13	500.7
75μm	348.10	261.7	86.40	12.3	14.41	587.1
Pan	446.40	434.2	12.30	0	2.05	599.4
Total			599.40			

Table 3. Sieve analysis for sample 3 (Enugu state mud)

Sieve size	Weight of sieve and sample	Weight of sieve	Weight of sample retained	Weight of passing	Percentage (%) sample retained	Cumulative retention
2.35mm	417.80	387.5	30.30	557.00	5.16	30.30
1.18mm	382.90	363.6	19.30	537.70	3.29	49.60
600μm	334.50	317.5	17.00	520.70	2.89	66.60
300μm	469.20	290.6	178.60	342.10	30.41	245.2
150μm	527.40	274.9	252.50	89.60	42.99	497.7
75μm	344.10	261.7	82.40	7.20	14.03	580.1
Pan	441.40	434.2	7.20	0	1.23	587.3
Total			587.30			

Table 4. Sieve analysis sample 4 (Niger state mud)

Sieve size	Weight of sieve and sample	Weight of sieve	Weight of sample retained	Weight of passing	Percentage retention	Cumulative retention
2.35mm	396.80	387.5	9.30	630.00	1.45	9.30
1.18mm	382.90	363.6	19.30	610.70	3.02	28.60
600μm	354.50	317.5	37.00	573.70	5.79	65.60
300μm	467.20	290.6	176.60	397.10	27.62	242.20
150μm	533.40	274.9	258.50	138.60	40.43	500.7
75μm	348.10	261.7	86.40	52.20	13.51	587.1
Pan	486.40	434.2	52.20	0.00	8.165	639.3
Total			639.30			

From the results of the sieve analysis shown on Tables 1, 2, 3 and 4, it was observed that about 92% of the grains of the mud from Delta and Enugu state are less than 150цm diameter while about 82% of the grains of mud sample from Niger state have diameter less than 300цm in the same vain about 87% of the grains are less than 300цm.

Tables 5, 6, 7 & 8 represents results obtained from the permeability tests and analysis carried out on the four samples from the study areas.

Table 5. Permeability test data for sample 1 (Delta state mud)

Level of lime present (%)	Flow quantity, Q (ml)	Head difference, h (mm)	$k = 0.159Q/h$ (mm/s)
0	513	72	1.12
20	527	76	1.15
30	483	65	1.17
40	510	68	1.19
			Average k = 1.15 mm/s

Table 6. Permeability test data for sample 2 (Ogun state mud)

Level of lime present (%)	Flow quantity, Q (ml)	Head difference, h (mm)	$k = 0.159Q/h$ (mm/s)
0	541	76	1.13
20	503	72	1.11
30	509	68	1.19
40	474	65	1.16
			Average k = 1.14 mm/s

Table 7. Permeability test data for sample 3 (Enugu state mud)

Level of lime present (%)	Flow quantity, Q (ml)	Head difference, h (mm)	$k = 0.159Q/h$ (mm/s)
0	531	76	1.11
20	506	72	1.12
30	503	68	1.18
40	482	65	1.18
			Average k = 1.14 mm/s

Table 8. Permeability test data for sample 4 (Niger state mud)

Level of lime present (%)	Flow quantity, Q (ml)	Head difference, h (mm)	$k = 0.159Q/h$ (mm/s)
0	23	76	1.09
20	508	72	1.12
30	505	68	1.18
40	478	65	1.17
			Average k = 1.14 mm/s

From the results displayed on the Tables 5, 6, 7 and 8, it was observed that the average permeability of the mud samples for Delta, Ogun and Enugu state samples was 1.15mm/s while that of Niger state is about 1.14mm/s for the four level of lime mixes while the result also show that there was an improvement of the permeability of samples with increase in the

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percentage of lime used.

The results shown on Tables 9, 10, 11 and 12 represent the result and analysis of results obtained from the Compression Test and analysis of the results obtained from the test carried on the four samples from the study areas.

Table 9. Compression test result for sample 1(Delta state mud)

Lime ratio (%)	Weight (10^{-2}kg)			Average weight	Strength			Average strength (kN)
	1st trial	2nd trial	3rd trial		1st trial	2nd trial	3rd trial	
0	6.00	5.88	6.20	6.03	47	46	55	49.3
20	6.00	5.95	6.02	5.99	48	45	56	49.6
30	6.02	5.79	6.01	5.94	53	46	54	51.0
40	6.01	5.98	5.79	5.93	48	45	56	49.6
50	6.05	5.99	5.98	6.01	49	53	52	51.3

Table 10. Compression test result for sample 2 (Ogun state mud)

Lime ratio (%)	Weight (10^{-2}kg)			Average weight	Strength (kN)			Average strength (kN)
	1st trial	2nd trial	3rd trial		1st trial	2nd trial	3rd trial	
0	6.10	5.86	6.20	6.05	46	53	45	48.0
20	6.05	5.96	6.02	6.04	48	54	46	49.3
30	6.02	5.79	6.00	5.94	46	56	45	49.0
40	6.00	5.84	6.00	5.95	47	56	55	52.7
50	6.02	5.92	6.02	5.99	55	56	46	52.3

Table 11. Compression test result for sample 3 (Enugu state mud)

Lime ratio (%)	Weight (10^{-2}kg)			Average weight	Strength (kN)			Average strength (kN)
	1st trial	2nd trial	3rd trial		1st trial	2nd trial	3rd trial	
0	6.10	6.20	6.20	6.97	56	45	45	48.7
20	6.20	6.02	5.86	6.03	56	54	45	51.7
30	6.02	6.00	5.96	5.99	54	56	46	52.0
40	6.00	6.00	5.79	5.93	55	56	46	52.3
50	6.00	5.92	5.84	5.92	52	53	53	52.7

Table 12. Compression test result for sample 4 (Niger state mud)

Lime ratio (%)	Weight (10^{-2}kg)			Average weight	Strength			Average strength (kN)
	1st trial	2nd trial	3rd trial		1st trial	2nd trial	3rd trial	
0	6.01	5.98	5.79	5.93	50	42	56	49.3
20	6.02	5.79	6.01	5.94	48	45	56	49.6
30	6.00	5.95	6.02	5.99	49	53	52	51.3
40	6.00	5.88	6.20	6.03	53	46	54	51.0
50	6.05	5.99	5.98	6.01	54	56	46	52.0

The results of Tables 9, 10, 11 and 12 shows a progressive increase in strength of the bricks made from the various levels of the lime mixes from all the sample areas. When the bricks were subjected to thermal stress it was observed that there were no significant changes that occurred on their dimensions but when the temperature was raised above 500°C it was observed that cracks appeared and the brick disintegrates.

Conclusion

An investigation into the effect of the addition of lime or calcium oxide to mud by considering some physical properties of samples from Delta, Ogun, Enugu and Niger states with a view of application for furnace lining has revealed that there is progressive increase of compressive strength with increase in lime addition. Permeability is improved and the setting time of the mud blocks reduced. However, their low thermal resistance makes it difficult for high temperature application for furnaces.

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