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Beneficiation of Ajaokuta Dolomite for Refractory and Foundry Applications

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Abstract:

Refractory materials are characterized by their high melting temperature and ability to retain their properties during high temperature service operations. This study was focused on investigating the suitability of Ajaokuta Dolomite for foundry application and as a refractory material. Internationally accepted methods for testing properties of refractories were adopted and the test results were compared with acceptable standards. Beneficiated dolomite sample was also used as an additive in a moulding sand and its performance was tested by casting an aluminium pattern and comparing the result with an aluminium pattern casted using the normal foundry sand without a dolomite. Results from this study such as; Loss on ignition (39.71), flowability (34%), swelling index (0.80), mouldability (84.3%), permeability (47.3%) and porosity (29.3%) are all in conformation with the standard requirements for refractory materials. Result from the tensile test also shows that Ajaokuta dolomite can be used as an additive for foundry sand.

Keywords —**Aluminium, Dolomite, Refractory, Foundry.**

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I. INTRODUCTION

The high temperature demands of foundry materials have necessitated the need to adopt refractory materials that can withstand high temperature in the excess of 538^{0}C [1]. Refractory materials find wide application in industries where high temperature application is required such as in foundry applications, glass manufacturing, steam boilers, and aerospace amongst others. The primary function of refractory materials is to help contain the heat generated during operation and minimize heat loss from the furnace, minimize operational cost, reduce energy requirement and enhance material durability during operations [2].

The gradual growth of industries in Africa have necessitated the need to harness and utilize locally sourced material for several industrial applications. Taking Nigeria as a case study where there exist, abundant mineral deposits, several mineral resources have been utilized with huge success in different applications most especially in the foundry industries.

One among the several factors militating against the progress of the foundry industries in Nigeria is the delay in delivery of refractory materials to these industries and this can be blamed on the competitive structure of the import-export trade and quantitative restrictions placed by strict government policies on importation of refractory materials [2]. One way out of this is to focus on studies aimed at characterizing locally sourced refractory materials, ascertain their commercial availability and suitability for industrial applications. A lot of research have been carried out to evaluate the available earth minerals in Nigeria and their suitability for industrial applications, however, an extensive review of the various studies considering all the key global players within this realm is not within the scope of this study but some of the studies that focus on exploring refractory materials within Nigeria will be cited.

[3], Investigated the properties of locally sourced dolomite from four different locations in Nigeria for refractory applications.

Dolomite samples from Ikpeshi, Osara, Ugya and Kwakuti were used in this study and the dolomite were physically and chemically characterized. The test results showed that dolomite is suitable for use as basic refractory materials in machine tools and steel making. Similarly, [4] characterized Abaji clay to assess their suitability for refractory and foundry application. The clay was sourced from three locations and physical and chemical characterizations were conducted on the clay samples. The mineralogical properties showed that the clay are mostly kaolinite and free quartz, and the chemical analysis showed that the clay is mostly composed of silica. It was concluded from the study that the clay deposit meets the standard requirement for it to be used as refractory clay and it was also asserted that the clay cannot be fired above 1100^{O}C. [5], carried out an assessment of some Nigerian kaolinite deposits for industrial applications. Clay samples from two areas; Ito and Idere, within Cross River State were collected, beneficiated and characterized by subjecting them to physical and chemical tests.

The results obtained from the test was in conformation with international standards such as; thermal shock resistance 21 cycles for Ito, cold crushing strength 13.33MN/m2 for Idere, apparent porosity of 29.41% for Idere and 27.27% for Ito, permeability of 88% for Idere and67% for Ito and linear shrinkage value of 9.20% and 7.73% for Idere and Ito respectively. It was concluded that the clay samples can find wide applications in brick making, floor tiles and stoneware.Other works inclue; [6], carried out chemical and mechanical characterization of clay samples from Kaduna state, [7] studied the effect of porosityon the shrinkage behavior of Ukpor and Nsu clay, [8] 2010, characterized Nahuta clay for industrial applications, [9] investigated the moulding properties of Nigerian silica-clay mixture for their application in foundry operations.

Among the available refractory materials in Nigeria, clay is the most widely utilized as evident from some of the above cited literatures. Little work has been done to ascertain the viability of using dolomite as binder for moulding sand despite the prospect they show as reported by [3], and that is the gap this study seeks to explore.

The aim of this study is to beneficiate dolomite materials sourced from Ajaokuta local government area of Kogi State and evaluate their viability as refractory materials and as a binder for foundry sand. The author intends to achieve this aim by using it as an additive in a foundry sand to cast aluminium and compare its mechanical properties to an aluminium casted using bentonite as a binder in a foundry sand.

II. MATERIALS AND METHODS

A. *Materials*

The dolomite sample was dug from Ajaokuta local government area of Kogi State. Ajaokuta is located in the North Central area of Nigeria with an area of 1,362 km^2 and it has a geographical coordinate of 7° 33′ 22″ N and 6° 39′ 18″ E. Bentonite was procured from conventional foundry shops and used as binder for sand mould.

B. *Methods*

Processing of Dolomite Samples

The resulting material was then left exposed to the air for five days to remove excess water and then fed into an oven furnace and set to a temperature of 110 ^{O}C to remove some inherent water.The resulting material was then fed into a pre-heated glost furnace and set to a temperature 1250 ^{O}C. This was done to foster the calcination of the raw dolomite and decompose into calcium oxide, magnesium oxide and carbon dioxide as represented in Equation 1.

$$CaCO_3MgCO_3 \rightarrow CaO + MgO + 2CO_2 \quad (1)$$

During the decomposition process, the carbon dioxide will be given up while the resulting dolomite was obtained and further grinded as shown in Fig.1.

Fig. 1: Grinded dolomite sample

Water was added to the grinded dolomite and fed into a milling machine where it was wet milled for six hours and this operation was followed by blunging operation for two hours to obtain a flowable suspension. The slip from the blunger was sieved with at 300µm, 200µm and 100µm sieve sizes respectively. Final sieve size of 100µm was collected and then passed through magnetic vibrators to remove the magnetic particles and the resulting dolomite was used for the study.

Moulding and Casting Process

In this study, two different mould was used. In one of the mould, foundry sand was used with bentonite as binder while in the other mould, foundry sand was used with dolomite as an additive and the mould was developed following the normal foundry procedures as reported in [10], while a cylindrical wooden pattern was used in the process. Aluminum was smelted in a crucible furnace and poured through the gating funnel into the mould and left for a one-hour period for the molten metal to solidify. This procedure was succeeded by cast shakeout and the solidified aluminium bars was removed from each of the mould and subjected to a tensile test.

Loss on Ignition

25g of the dolomite sample was weighed into a crucible and then transferred into a glost furnace set to a temperature of about 900 ^{O}C for 2 hours 30 minutes and then later left to cool in a desiccator. The loss on ignition was calculated using Equation 2.

$$L.O.I = \frac{m_2 - m_3}{m_2 - m_1} \quad (2)$$

Where m_2 = Mass of the dolomite sample and crucible before firing, m_1= Mass of dried crucible and m_3 = Mass of heated dolomite and crucible.

Flowability and Mouldability Index

This test was carried out as reported by [3]. About 30g of the dolomite sample was fed into the flowability and mouldability machine comprising of a rotating cylindrical sieve.

During the process of rotation, the mix that passes through the sieve was weighed and recorded. The weight was then divided by two to obtain the mouldability index while the flowability index wasdepicted by relationship between the mass of sand falling through the sieve and the total mass expressed in percentage.

Swelling Index

The swelling index was determined according to ASTM-D5890 [11]. About 3g of the dried dolomite samples was spread in a 100ml calibrated cylinder with a 0.2g increment and allowing 10 minutes between additions of the samples to allow full hydration of and settlement of the dolomite at the bottom of the cylinder and this procedure was maintained until the 3g of dolomite has been fed into the cylinder and the level was noted and recorded. About 25ml of water was added to the sample in the cylinder and left for 24 hours. After 24hrs, the remaining water in the sample was decanted and the sample was re-weighed. The swelling index was determined as a ratio of weight of the hydrated dolomite to that of the dry one.

Permeability Index

Permeability is a measure of the ease in which fluid can percolate a measured volume of the dolomite sample. In accordance with [12], permeability test was done by pressing the dolomite sample
mixed with binder (bentonite) and water into a cylindrical mug. The pressing was done using a ram and a hydraulic press. The resulting cylindrical sample was then placed in a Falling Head Permeability apparatus for about 15 to 20 minutes. The permeability coefficient was calculated using Equation (3) [12].

$$P_m = \frac{Vh}{APt} \quad (3)$$

Where P_m is the permeability coefficient, V = Volume of air, h = Height of the cylindrical sample, A = Surface area of the cylindrical sample, P = Pressure differences and t = Time.

Apparent Porosity

The apparent porosity was determined using the boiling method as reported by [13]. In this procedure, test sample of dimension 50 x 50 x 20 mm was cut and prepared from the fired sample and oven dried at a 110 ^{O}C while the sample was weighed and recorded as 'D'. The sample was then suspended in a beaker filled with distilled water and boiled for two hours, left to cool at room temperature, re-weighed and recorded as 'S'. The specimen was then removed from water and the weight was recorded as 'W'. The apparent porosity was then calculated using Equation 4;

$$Apparent\ Porosity = \frac{W-D}{W-S}\ x\ 100 \quad (4)$$

Tensile Test

The casted aluminium sample from the sand mould and dolomite mould were both subjected to tensile test. The tensile test was carried out according to ASTM D638. The tensile test was carried out using Hounsfield Tensometer which was designed to stretch the test samples at constant rate and simultaneously measure the applied load and the resulting elongation using extensometer. The specimen was machined according to the specification shown in Fig. 2

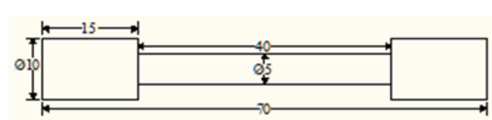

Fig. 2: Machined Specimen

Two tensile test specimen with thickness(t) mm, length (L) mm, and width(b)mm, were cut for the tensile test. the tensile strength can be determined using Equation 5; [14]

$$\sigma_t = {}^{\rho}/_{A} \qquad A = t * b * L$$

$$\sigma_t = \frac{\rho}{t*b*L} \qquad (5)$$

III. RESULTS AND DISCUSSIONS

A. *Chemical Compositions of the Raw Dolomite Sample*

X-ray fluorescence spectroscopy was used in the chemical characterization of the raw dolomite sample and the test was done at the National Geoscience Research Laboratory (NGRL) Kaduna State Nigeria, and the results are as represented in Table 1.

TABLE 1: CHEMICAL COMPOSITION OF RAW DOLOMITE SAMPLE

Sample	CaO	MgO	SiO_2	Al_2O_3	Fe_2O_3	Na_2O	MnO_2	L.O.I
Ajaokuta raw dolomite sample	33.78	20.07	0.47	0.13	0.42	0.21	0.07	39.71

From Table 1, it can be seen that the oxides of calcium and magnesium are the dominant materials present in the raw dolomite sample and according to [15], the refractory properties of dolomite is a function of the oxide of magnesium present in the sample. The value of magnesium present in the dolomite sample as depicted in the Table 1 is about 20.07% which is close to the value of the conventional dolomite. With low silica content of about 0.47%, this is desirable for refractory materials as too high silica content can negatively affect the strength of refractory materials as reported by [16].

Furthermore, the low percentage of the oxides of silica and iron shows that the dolomite sample is a low fluxing oxide and oxides like these are characterized with high crushing strength, high melting point and high slag resistance [12].

B. *Flowability, Swelling Index, Mouldability and Permeability*

The results for the flowability, swelling index, mouldability and permeability are presented in Table 2.

Table 2: Properties of the Raw dolomite samples

Specimen	Flowability (%)	Swelling index	Mouldability (%)	Permeability (npm)	Apparent Porosity (%)
Ajaokuta Dolomite	34	0.80	84.3	47.3	29.3

From Table 2, it can be seen that the flowability value of raw dolomite sample is 34% and according to the scale of flowability for refractory materials, flowability values between 31 to 35% is considered good for refractory materials [12].

The value for the swelling index as shown in Table 2 is within the acceptable range.
As reported by [18], if the swelling index of a refractory
material is too high, say above 1.7 [3], there is high tendency for the material to absorb moisture and swell such that upon drying, they shrink and leave large voids within the material.
The mouldability value of 70.3% was considerably high according to [19] and this implies that using the raw dolomite sample as a binder in sand casting will constitute plasticity and green strength to the sand. The permeability of the dolomite sample was determined to be 47.3 which is still within the acceptable range of 25-90 [20]. It is however desirable that a refractory material should be permeable especially under the influence of gases and liquid so as to reduce leakage of gas and fluid penetration in operation [21].

C. *Apparent Porosity*

From Table 2, the apparent porosity of the raw dolomite sample is 29.3% and this shows that they fall within the standard range required for fire clay brick which is within the range of 20 – 30% according to [22].

D. *Tensile Test*

In order to ascertain the suitability of the raw dolomite as a binder for sand cast, two separate moulds were made, one with moulding sand and the other with dolomite as an additive. The two separate mould were then used in casting an aluminium pattern and then machined into a dumbbell shape for tensile test according to ASTM D638. The machined figure is as shown in Fig. 3.

Fig.3: Casted and Machined Aluminium patternfor Tensile Test

The results obtained from both mould are shown in Table 3 and 4. From the test, the extension, the stress components and strains were recorded.

Table 3: Result from tensile test on Aluminium casted from mould containing Dolomite

S/N	**Load (kN)**	**Extension (mm)**	**Increase in length** $l_1 = l_o + e$	**Engineering Stress (MPa)** $\sigma_o = P / A_o$	**Engineering Strain** $\varepsilon_0 = (l_1 - l_0) / l_0$	**True Stress (MPa)** $\sigma = \sigma_0(1 + \varepsilon_0)$	**True Strain** $\varepsilon = \ln(1 + \varepsilon_0)$
1	1.9	2.31	42.31	96.74	57.75×10^{-3}	102.33	56.14×10^{-3}
2	2.7	2.70	42.70	137.47	67.50×10^{-3}	146.75	65.32×10^{-3}
3	2.7	2.89	42.89	137.47	72.25×10^{-3}	147.40	69.76×10^{-3}
4	2.6	5.33	45.33	132.39	133.25×10^{-3}	150.03	125.09×10^{-3}
5	2.5	7.66	47.66	127.31	191.50×10^{-3}	151.68	175.21×10^{-3}
6	2.7	10.66	50.66	137.47	266.50×10^{-3}	174.11	236.26×10^{-3}

Table 4: Result from tensile test on Aluminium casted from Sand Mould (Control Specimen)

S/N	**Load (kN)**	**Extension (mm)**	**Increase in length** $l_1 = l_o + e$	**Engineering Stress(MPa)** $\sigma_o = P / A_o$	**Engineering Strain** $\varepsilon_0 = (l_1 - l_0) / l_0$	**True Stress (MPa)** $\sigma = \sigma_0(1 + \varepsilon_0)$	**True Strain** $\varepsilon = \ln(1 + \varepsilon_0)$
1	1.9	2.35	42.35	96.74	58.75×10^{-3}	102.42	57.09×10^{-3}
2	2.7	2.83	42.83	137.49	70.75×10^{-3}	147.21	68.34×10^{-3}
3	2.7	2.97	42.97	137.49	74.25×10^{-3}	147.69	71.62×10^{-3}
4	2.6	5.69	45.69	132.39	142.25×10^{-3}	151.22	133.00×10^{-3}
5	2.5	8.35	48.35	127.31	208.75×10^{-3}	153.89	189.59×10^{-3}
6	2.7	10.63	50.63	137.49	265.75×10^{-3}	174.03	235.66×10^{-3}

Where $A_o = \frac{\pi d^2}{4}$ and $d = 5.00$mm and $l_o = 40$mm.

From Table 3 and 4, the same amount of loads was applied to the sample casted using the dolomite containing mould and the sand mould cast and it can be seen from the table that the extension of the material as a result of the load application increases rapidly for the aluminium bar casted from the sand mould compared to that casted using the dolomite containing mould.
A graphical representation of the stress strain curve of the two casted aluminium are presented in Fig. 4 and 5.

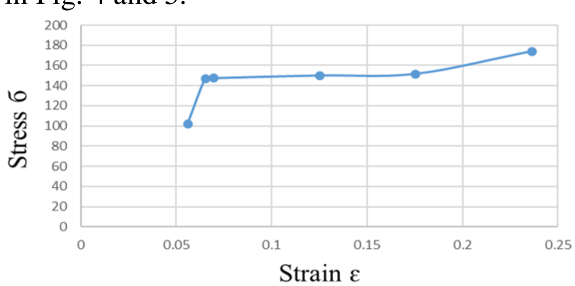

Fig. 4: Stress Strain diagram of failure characteristics of Almuminium casted from dolomite containing mould

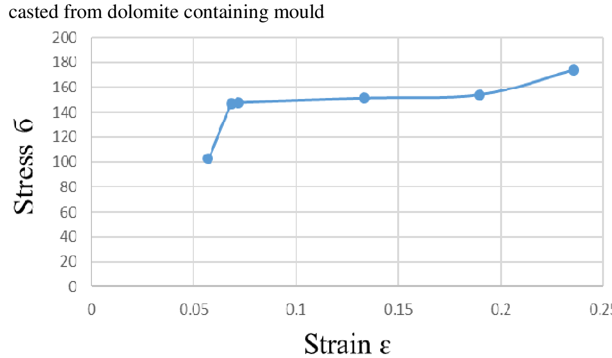

Fig. 4: Stress Strain diagram of failure characteristics of Almuminium casted from sand mould

From the stress strain diagram, the value of the ultimate tensile strength obtained from the dolomite containing mould and sand mould are 147.4 MPa and 147.7 MPa respectively. It can be seen that there is no significant improvement in the value of the tensile strength despite the addition of dolomite but the slight increase in tensile strength and reduced elongation is an indication that an appreciable value of dolomite would have increased the tensile strength. Physical observation of the product, the Aluminium casted using dolomite containing mould have better surface finish compared to the other.

IV. CONCLUSIONS

The following conclusions were drawn based on the result obtained from the study;

1. From the chemical analysis result, it can be seen that the dolomite sample under consideration possess the requisite chemical components such as oxides of magnesium and calcium, that makes them viable as refractory material.
2. Results obtained from tests such as; flowability test, swelling index, mouldability, permeability and apparent porosity are in compliance with the set standard requirements for refractory materials.
3. The tensile strength of the samples casted using the mould containing dolomite was slightly higher than the product casted using the conventional foundry sand and this implies that dolomite serves as a good additive for foundry sand.

REFERENCES

[1]. ASTM C17. Standard Terminology Relating to Refractories, available at https://www.astm.org/Standards/C71.htm. Accessed August, 2019.
[2]. M. M. Muhammadu, "An Investigation on Refractory Clays Properties for Application in Metallurgical Industries in Nigeria", *International Journal of Advanced Research*, 1 (6): 200 – 207, 2005.
[3]. H.I. Moorkah and M.S. Abolarin, "Investigation of the Properties of Locally Available Dolomite for Refractory Application", *Nigerian Journal of Technology,* 24(1): 79-86, 2005.
[4]. G. O. Mathew, S. S. Owoeye, "Characterization of Abaji clay deposits for refractory applications", *Leonardo Electronic Journal of Practices and Technologies",* 29: 115 – 126, 2016.
[5]. O. F. Aje and B. M-K. Achu, "Assessment of The Industrial Potentials of Some Nigerian Kaolinitic Clay Deposits. *European Journal of Engineering and Technology",* 5(2): 48 – 56, 2017.
[6]. J. U. Manukaji, "Chemical and mechanical characterization of clay samples from Kaduna state", *International Journal of Engineering of Research and applications,* 3(2):1-5, 2013.
[7]. I.C. Nwoye, "Effect of porosity on the shrinkage behavior of Ukpor and Nsu clays", *Journal Engineering applied science*, 3(1, 2):27-30, 2008.
[8]. E.E. Nnuka and C. Enejor, "Characterisation of Nahuta clay for industrial and commercial applications", *Nigerian journal of Engineering and materials*. 2(3)9-12, 2010.
[9]. Olasupo O. A., *et al,* "Moulding properties of a Nigerian silica–clay mixture for foundry use", *Journal of Applied Clay Science*, 45: 244-247, 2009.
[10]. M.P. Groover, Introduction to manufacturing processes, John Wiley & Sons, 2012
[11]. Astm D5890. Standard Test Method for Swell Index of Clay Mineral Component of Geosynthetic Clay Liners. Available at https://www.astm.org/Standards/D5890.htm, Accessed August, 2018.
[12]. T. Degawa *et al*, "Development of CaO MgO refractories and their effects in refining mechanism of extremely clean steel", *Proceedings of the 2nd International conference on refractories Tokyo*, pp842-846, 1987.
[13]. S. B. Hassan, *Modern refractories: production, properties, testing and application*, Zaria, Timo Commercial Printers, 2005.
[14]. RS. Khurmi and JK. Gupta. *A Textbook of Machine Design*. Eurasia Publishing House (PVT), New Delhi, India, 2005.
[15]. J. H. Chesters, *Refractories Productionand Properties, the Metal Societies",* London, 2nd Edition 1975.
[16]. J. H. Chatillon,*et al*, "Clean Steel and Clean Environment with fired Refractories *Proceedings of internationalconference on refractories in China",* p 433 -451.1988.
[17]. S. Mohan, "Compression physics of pharmaceutical powders: A review*", International Journal of Pharmaceutical Powders and Research"*, 3(6): 1580-1592, 2012.
[18]. J. D. Rogers, R. Olshansky, and R. B. Rogers, "Expansible sand", Available at https://web.mst.edu/~rogersda/expansive_soils/DAMAGE%20TO%20FOUNDATIONS%20FROM%20EXPANSIVE%20SOILS.pdf, accessed August, 2019.
[19.] F. O. Edoziuno, J. U. Odo and E. E. Nnuka, "Effect of Ukpor clay content on the properties of synthetic moulding sand produced from River Niger sand", *International Journal of Research in Advanced Engineering and Technology,* 1(3): 12-16, 2015.
[20]. E.O. Obadinma, "Development of Refractory Bricks for Heat Treatment Facilities", *Journal of Science and Technology Research*, 2(2):13-17, 2003.

[21]. S.B. Hassan, and J.O. Adewara, "Refractory properties of someNigerian clays", *Nigerian Society of Engineers Transcript*, 28(3): 21-25, 1993.
[22]. O. J. Omowumi, "Characterization of some Nigerian Clays as Refractory Material for Furnace Lining", *Nigerian Journal of Engineering Management,* p. 1-4, 2004

