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Geochemical Assessment of Obajana Marble for its Industrial Applications

[1]Jethro M.A., [2]Shehu S.A., [3]Ayoola J.O. and [4]Ibrahim M.O.
[1,2,3,4]Department of Civil and Mining Engineering, Confluence University of Science and Technology, Osara. Kogi State Nigeria.
E-mail: adebolajethro@yahoo.com Orcid Id 0000-0003-1017-3311; shehuthefirst@yahoo.com, Orcid Id 0000-0001-9022-1277 olajohson014@gmail.com and ibrahimmo@custech.edu.ng

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Abstract

This study aims to assess the potential of Obajana marble as a raw material in the production of cement and other industrial applications by evaluating its mineralogical and chemical composition. Five samples from Obajana were analyzed using energy dispersive XENEMETRIX XRF and Rigaku Mininflex XRD to ascertain its mineralogical and chemical composition respectively. The tests explored the applicability of marble as a replacement for limestone in clinker formation which reduces the environmental impact of cement production while maintaining comparable chemical and mechanical properties; the incorporation of marble powder as a Supplementary Cementitious Materials (SCM) and utilization in metal production have enhanced workability, durability, and strength, contributing to reduced clinker consumption and carbon emissions. The presence of calcium carbonate ($CaCO_3$: 91.99 %), calcium oxide (CaO: 92.42%), silica (SiO_2: 1.38–5.65 %), alumina (Al_2O_3: 1.50–3.82%), and iron oxide (Fe_2O_3: 0.29%) in Obajana marble supports its role in clinker formation by promoting cementitious compound development and function as a fluxing agent in pyrometallurgical processes in metal smelting. The high $CaCO_3$ and minor SiO_2, and Al_2O_3 content, enables Obajana marble serve as a cost-effective filler, improving packing density, microstructure, and mechanical properties of concrete. The findings underscore the potential suitability of Obajana marble in promoting resource efficiency, circular economy principles, and sustainable building materials. With a high CaO content of 92.93% and minimal impurities such as SiO_2, Al_2O_3, and Fe_2O_3, the marble meets key chemical criteria for use in cement and lime production. Its low MgO and Fe_2O_3 levels further suggest suitability for white cement and high-grade construction materials. The trace elements present are within acceptable industrial limits, reinforcing its potential for eco-friendly and versatile applications. This research provides valuable insights into the role of Obajana marble in advancing sustainable construction practices and reducing dependency on imported raw materials by integrating detailed geochemical characterization of Obajana marble with its industrial suitability for cement and construction material production and application.

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1.0 Introduction

Carbonate rocks, including limestone and marble, are primarily sedimentary rocks composed of carbonate minerals [1]. In Nigeria, marble deposits are extensively found within the Precambrian Basement Complex and are commonly associated with the Schist Belts [2] [3] [4]. These Schist Belts exhibit distinct petrological, structural, and metallogenic characteristics, predominantly occupying north-south trending troughs. They are particularly prominent in the western region of the country [5]. Many of these marble deposits remain largely untapped, primarily due to a lack of comprehensive data on their composition, which is crucial in determining their suitability for industrial applications [6].

The application of marble is influenced not only by its chemical composition but also by its petrographic properties. Key factors such as mineralogical composition and grain size, which are easily identifiable physical characteristics, play a significant role in determining the strength, visual appeal, and color of marble, ultimately affecting its suitability for various industrial uses [7] [8].

Marble deposits in Nigeria, including those in Obajana, have historically played an important role in providing raw materials for industries like construction, fertilizer production, and chemicals. Additionally, these marble rocks have the potential to be used to extract valuable metals like gold (Au), lead (Pb), silver (Ag), tin (Sn), copper (Cu) bearing minerals, and certain silicate minerals, especially when subjected to hydrothermal processes. This study therefore assesses the chemical composition of Obajana marble to determine its suitability for cement production, construction aggregates, and other building materials.

1.1 Application of Marble in Construction

C Depending on the project's requirements, construction materials vary widely in type, properties, and applications [9]. Marble is a natural stone used in construction for centuries due to its aesthetic appeal, durability, and versatility [10]. Generally, marble is an important ingredient in the production of cement. Cement is described as a material with adhesive and cohesive properties capable of bonding material fragments into a compact whole [11]. Marble is prized for its unique veining patterns, wide range of colors, and polished finishing, making it a popular choice for both structural and decorative applications. The choice of construction materials depends on the specific needs of the project, including structural requirements, climate, and intended use. Advances in technology and sustainability are driving innovation in this field, leading to the development of smarter and more eco-friendly materials.

1.2 Description of Study Area

The study area lies between longitude 6°10°E and 6°30' East of the Greenwich meridian and Latitude 7°40'N and 8°00'N North of the equator, as shown in Figure 1. Obajana is home to the Dangote Cement Plant in Kogi State, which is the largest cement plant in Sub-Saharan Africa and ranks among the largest cement plants globally [12].

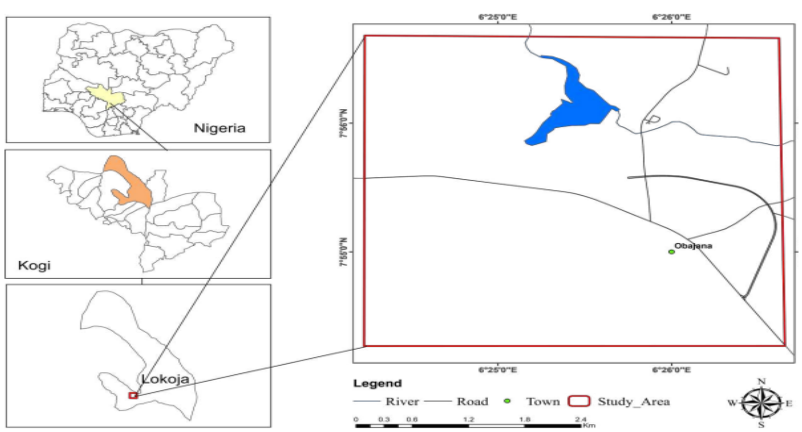

Figure 1: Map showing the Study Area

2.0 Methodology

Hundred-kilogram (100Kg) of broken marble rock samples were gathered from Obajana marble deposits, to allow for an investigation of the marble's chemical and mineralogical composition. The mineralogical composition of the broken-field samples collected from the Obajana deposit was analyzed using a Rigaku Miniflex XRD equipment. The field samples were further broken and ground with a laboratory-sized crusher and pulverize to a particle size <75 µm for its engineering applications. The Powdered rock samples were then subjected to analysis using an energy dispersive Genius IF XENEMETRIX XRF equipment for their elemental composition with the spectrum analysis conducted on an XRS-FP Software. The XRD on the other hand, the sample was analyzed on an RIR Quantification to match the mineral phases and generate the report for both the qualitative and the quantitative analysis. Comparative analysis of the chemical composition of the marble sample was carried out with ASTM and European committee for standards to ascertain its suitable industrial applications.

3.0 Results and Discussion

3.1 Mineralogical Assessment

The result of the mineralogical composition of five (5) marble samples taken from Obajana is presented in Table 1, and this is plotted as a histogram showing the percentage composition of the constituent minerals in Figure 2. From the Figure 2, calcite mineral ($CaCO_3$) is the most dominant mineral with an average percentage composition of 91.99 %. The sample composition also comprises quartzite (SiO_2), Albite (K/Na.SiO_2), and lime (CaO) of average percent composition of 7.70 %, 2.3 %, and 0.89 %, respectively. These results confirmed marble as a metamorphic rock with calcite mineral ($CaCO_3$) being the most dominant mineral [13].

Table 1: Result of Mineralogical Composition

Samples	% Mineral Composition			
	Calcite ($CaCO_3$)	Quartz (SiO_2)	Albite (K/Na. $AlSiO_3$)	Lime (CaO)
A	89.11	8.12	1.23	1.53
B	93.41	4.10	1.83	0.52
C	90.59	5.94	2.62	0.74
D	92.15	6.17	1.02	0.63
E	94.73	3.9	0.8	0.51
% Avg. Comp.	91.99	5.65	1.50	0.79

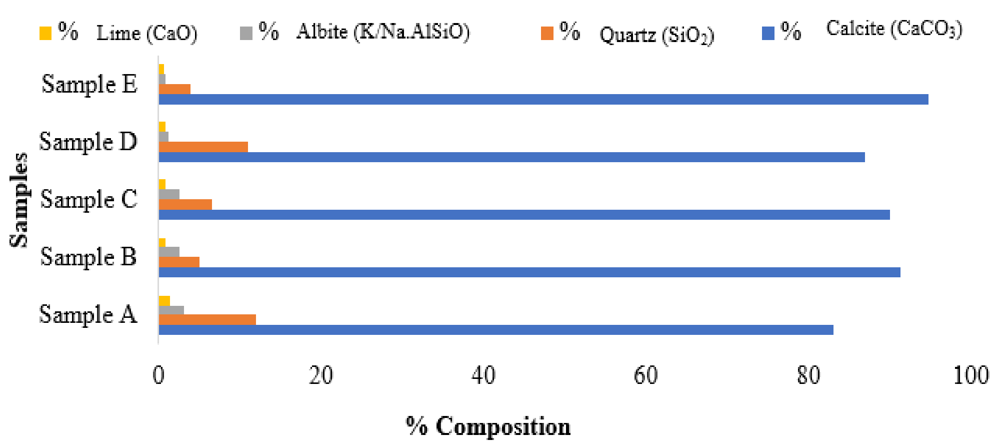

Figure 2: Mineralogical Percent Composition

3.2 Chemical and Elemental Compositions

The results of elements contained in the marble samples are presented in Table 2 and the chart showing the elemental composition of the five samples is presented in Figure 3.

Table 2: Result of Elemental Composition

Samples	% Elemental Composition										
	Ca	Si	Al	Sn	Fe	Ba	Cl	Zr	Ta	Mg	O
A	66.42	0.11	2.63	0.36	0.21	0.14	0.24	0.11	0.12	0	29.35
B	62.71	1.19	2.19	0.4	0.33	0.13	0.31	0.1	0.03	1.96	30.1
C	64.88	1.15	2.53	0.38	0.3	0.01	0.3	0.11	0.01	0.09	29.9
D	66.17	0.22	2.53	0.49	0.26	0.04	0.39	0.1	0.15	0	29.34
E	66.01	0.59	2.29	0.43	0.28	0.12	0.31	0.12	0.03	0	29.48
	65.24	0.65	2.43	0.41	0.28	0.09	0.31	0.11	0.07	0.41	29.63

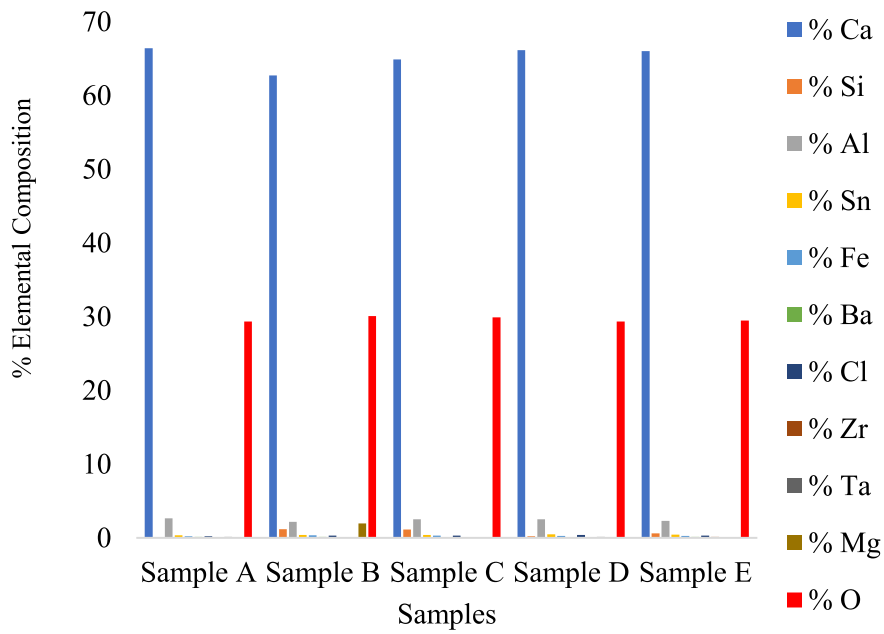

Figure 3: Percentage Elemental Composition

The Calcium (Ca) and Oxygen (O) elements account for 65.24 % and 29.63%, respectively, indicating the carbonaceous history of the rock, classifying it as sedimentary by origin. Other elemental components of the sample are associated with common marble mineral.

Table 3: Result of Chemical Composition

Samples	% Chemical Composition										
	CaO	SiO_2	Al_2O_3	SnO_2	Fe_2O_3	BaO	Cl	ZrO_2	Ta_2O_5	MgO	K_2O
A	92.93	0.25	4.98	0.45	0.30	0.16	0.24	0.15	0.15	-	0.07
B	87.75	2.55	4.14	0.51	0.47	0.15	0.31	0.14	0.04	3.26	-
C	90.78	2.47	4.79	0.48	0.44	0.01	0.3	0.15	0.02	0.16	-
D	95.52	0.45	2.71	0.24	0.13	0.01	0.06	0.06	0.02	-	-
E	95.13	1.22	2.46	0.21	0.14	0.05	0.50	0.08	-	-	-
Avg. Comp.	92.42	1.38	3.82	0.38	0.29	0.08	0.28	0.12	0.05	-	-

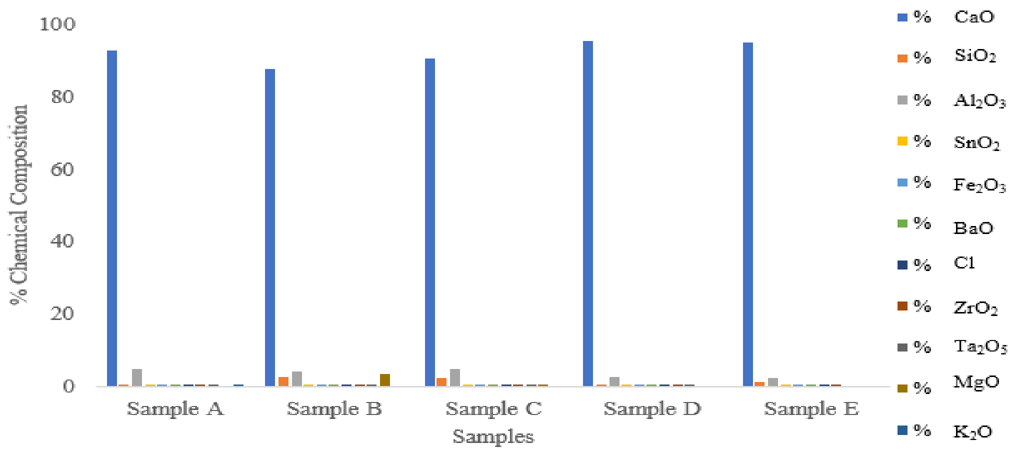

Figure 4: Chemical Analysis of Samples

The result of the chemical analysis in Table 3 shows that the marble samples from Obajana contain high Calcium Oxide (CaO) which is an average of 92.42 %. Other constituents of the sample are Al_2O_3, SiO_2, and Fe_2O_3 with an average composition of 3.82 %, 1.38 %, and 0.29 % respectively.

Table 4: Comparative study of Obajana marble in relation to International Standards

Chemical Component Relating to Standards	**Obajana Marble (Avg. %)**	**ASTM C595/C150 Requirement**	**EN 197-1 Requirement**	**Comparative Remarks**
CaO	92.93	42% (equivalent to ≥75% $CaCO_3$)	≥75% $CaCO_3$ (42% CaO)	Exceeds requirement
SiO_2	0.25	No specific limit (low % preferred)	No specific limit	Acceptably low
Al_2O_3	4.98	No specific limit	No specific limit	Can aid hydration
Fe_2O_3	0.30	Combined (SiO_2 + Al_2O_3 + $Fe_2O_3 \leq 5\%$)	Same as ASTM	Acceptable (total = 5.53%)
MgO	0.68	≤ 5.0%	≤ 4.0%	Excellent (none detected)
Cl	0.24	≤ 0.10–0.20% (optional spec)	≤ 0.10% (water-soluble)	Slightly above EN limit and further testing needed
K_2O	0.07	No specific limit	≤ 0.60% (when specified as low alkali cement)	Trace level
Other Trace Oxides (SnO_2, BaO, ZrO_2, Ta_2O_5)	≤ 0.45 each	Not specified	Not specified	Considered inert at trace levels

Sulfur Trioxide (SO_3)	-	3.0 (for Types I & II)	≤ 3.5% for CEM I and CEM II/A-L, CEM II/A-LL; ≤ 4.0% for other types	Not tested
Loss on Ignition (LOI)	-	3.0	≤ 5.0%	Not Tested
Insoluble Residue	-	0.75	≤ 5.0%	Not tested
Tricalcium Aluminate (C_3A)	-	15.0 (Type I)	No specific limit	Not tested

Table 4 shows the comparative study of Obajana Marble sample to the standard specifications that ensure the quality and performance of Portland cement in various construction applications according to ATM C150 and EN197-1 respectively. According to these standards, limestone materials incorporated into blended cements must contain at least 75% $CaCO_3$ (EN197-1), equivalent to approximately 42% CaO (ATM C150). The Obajana marble sample possess a higher average $CaCO_3$ content of 91.99% and CaO content of 92.44 %, respectively indicating that Obajana marble is very suitable for cement production.

3.3 Suitability of Obajana Marble for Production of Construction Materials

3.3.1 Obajana Marble as Replacement for Limestone Clinker Production

Ordunarily, limestone is the primary ingredient in cement clinker production, which is produced by heating a mixture of limestone ($CaCO_3$), silica (SiO_2), alumina (Al_2O_3), and iron oxide (Fe_2O_3) at high temperatures. Based on the high composition of calcite ($CaCO_3$) in the Obajana Marble sample at an average of 91.99 % and lime (CaO) of 0.79 %, marble from this site can be used to replace limestone in clinker production for cement [11]. This has been seen to be more economical for cement production, reducing environmental impact and energy consumption in cement production plants [14] [11].

3.3.2 Marble as a Supplementary Cementitious Material (SCM)

Marble obtained from the Obajana site can be effectively utilized as a supplementary additive in cement production when broken, ground, and processed into fine marble powder. The high calcium oxide (CaO) content (92.42%) in the marble closely aligns with the composition of limestone powder, which is widely accepted as a Supplementary Cementitious Material (SCM) in cement production when compared to ASTM C150 (Table 4) and EN 197-1 (Table 5) standards [19][20]. Additionally, the presence of Al_2O_3 (3.82%), SiO_2 (1.38%), and Fe_2O_3 (0.29%) remain within acceptable ranges for SCMs supporting its role in enhancing cement hydration through filler effects and potential pozzolanic reactions. While not as reactive as traditional pozzolans, finely ground marble powder can improve cement packing density, reduce porosity, and optimize hydration, making it a viable SCM in construction applications. Studies have shown that replacing 5–15% of cement with marble powder enhances the strength and durability of concrete [15]. This improves workability, enhances strength, and reduces the carbon footprints emanating from cement plants [16] [17] [18].

3.3.3 Marble as a Valuable Additive in Metal Extraction

Metals such as iron, aluminum, and copper are valuable components of construction materials, and the application of marble in extracting these metals is crucial for their production. The extraction of metals like iron requires high-purity marble containing a high percentage of calcium carbonate and calcium oxide content. The Obajana marble, with a high calcium carbonate ($CaCO_3$) content of 91.99% and calcium oxide (CaO) content of 92.42%, is valuable for metal extraction purposes [21][22]. In blast furnace operations, Obajana marble ($CaCO_3$) acts as a fluxing agent, replacing limestone to remove impurities such as silica (SiO_2), phosphorus (P), and sulfur (S) from iron ore [23]. Additionally, the high CaO content (92.42%) in the marble ensures efficient slagging, improving metal purity and reducing refractory wear in furnaces [15] [24].

3.3.4 Functional and Economic Benefits

Beyond the technical suitability of Obajana marble, it offers significant economic and environmental advantages compared to other marble deposits in Nigeria. Its local availability near major cement production facilities such as the Dangote Cement Plant in Kogi State reduces transportation costs and reliance on imported SCMs. The application of such a locally sourced material not only promotes cost efficiency but also contributes to sustainable industrial applications in construction by lowering the clinker factor and associated carbon emissions.

4.0 Conclusion

Obajana Marble, due to its high calcium carbonate ($CaCO_3$) content of 91.99 %, silica (SiO_2), alumina (Al_2O_3), and iron oxide (Fe_2O_3) levels, has proven to be a versatile material that is applicable in the production of some vital construction materials. In cement manufacturing, marble serves as a raw material for clinker production, a supplementary cementitious material (SCM), and an inert filler, contributing to improved workability, strength, and sustainability of concrete. Its use reduces the heavy reliance on traditional limestone, reduces carbon emissions, and enhances the durability of cement-based materials. In metallurgical applications, marble functions as a fluxing agent in iron, steel, copper, and aluminum smelting thereby facilitating the removal of impurity and slag formation. Thus, Obajana marble is highly valuable and preferable in many industrial applications due to its location, extremely high CaO content, Significant cost-saving potential in both cement and metallurgical applications, abundance and accessible local supply.

In conclusion, the Obajana marble sample satisfies the key chemical requirements for clinker production, SCM, serves fluxing agent and inert filler. Its uses and applications offer additional logistical and environmental benefits. These attributes make it a strategic and preferable alternative for cement producers seeking high-performance, locally available SCMs in compliance with international standards.

5.0 Recommendation

The overall integration of marble in cement and metal extraction processes highlights its potential as a cost-effective and environmentally friendly material. Future research should focus on optimizing its applications in green metallurgy, alternative cement technologies, and rare earth element (REE) extraction, ensuring more sustainable industrial operations.

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Conflict of Interest Statement

The authors affirm that there are no competing interests or conflicts of interest associated with this work.

Author Contributions

All authors collaborated on the research, contributed to the interpretation of results, and approved the final version of the manuscript.

References

[1] Odokuma-Alonge, O., Isaac, O., Ogbamikhumi, A. and Alonge, P. O., (2019). *Geochemical Analysis of Marble from Ubo River Area: Implication for Paleo Environmental Conditions.* FUW Trends in Science & Technology Journal, e-ISSN: 24085162; p-ISSN: 20485170; December, 2019: Vol. 4 No. 3 pg. 835 – 840.

[2] Rahaman, M. A. (1988). *Recent advances in the study of the Basement Complex of Nigeria*. Precambrian Geology of Nigeria, 11–43.

[3] Obaje, N. G. (2009). *Geology and mineral resources of Nigeria*. Springer Berlin, Heidelberg. ISBN: 978-3-540-92684-9; ISSN: 0930-0317, pg. 221. First Edition.

[4] Ajibade, A. C., Woakes, M., & Rahaman, M. A. (1987). *Proterozoic crustal development in the Pan-African regime of Nigeria*. Geological Society Special Publication, 17(1), 259–271.

[5] Elueze, A.A., Jimoh, A.O., Aromolaran, O. K., (2015). *Compositional Characteristics and Functional Applications of Obajana Marble Deposit in The Precambrian Basement Complex of Central Nigeria*. Ife Journal of Science vol. 17, no. 3 (2015), pg. 591.

[6] Akinola O. O. and Adebayo O. F., (2023). *Mineralogy and Geochemistry of a Marble Deposit, Owan-East, Southwestern Nigeria: Implications for Protolith and Industrial Uses.* Elixir Earth Science 177, pg. 56824 – 56830.

[7] Ashraf, M., Khan, A. S., & Ahmad, Z. (2018). *Influence of Petrographic Characteristics on the Durability and Strength of Marble.* Journal of Construction and Building Material, Vol. 173 No. 1, pg. 435–447.

[8] Siegesmund, S., and Török, Á. (2019). *Natural stone resources for historical monuments*. Geological Society, London, Special Publications.

[9] Domone, P., and Illston, J. (2010). *Construction Materials: Their Nature and Behaviour*. CRC Press.

[10] Mamlouk, M. S., and Zaniewski, J. P. (2016). *Materials for Civil and Construction Engineers*. Pearson Education. ISBN: 9781292154411. Pgs 1-664.SI Edition.

[11] Ayoola J.O., Joseph O.F., and Agagwu J. (2020). *Quantitative Optimization of Cement Rotary Kiln for Heat Reduction in Clinker Production.* International Journal of Advances in Engineering and Management (IJAEM) Volume 2, Issue 5, pp: 11-18. ISSN: 2395-5252

[12] Olanrewaju C.A., Micheal B.A. (2022). Cement Industry and Climate Change in Nigeria: A Case Study of Dangote Obajana Cement Plant. Universal Journal of Geoscience, 9(2), 21 - 29. DOI: 10.13189/ujg.2022.090201.

[13] Geology Science. (2023). *Marble: Metamorphic rock*. Geology Science. Retrieved February 23, 2025, from https://geologyscience.com/rocks/metamorphic-rocks/marble/#google_vignette

[14] Ali, A. A., El-Dieb, A. S., and Reda, S. M. (2020). *Effect of marble powder on the properties of concrete: A sustainable approach.* Journal of Building Engineering, 32, 101714.

[15] Singh, M., Srivastava, A., and Bhunia, D. (2021). *Performance of concrete incorporating marble powder: A review.* Materials Today: Proceedings, 43, 2804–2812.

[16] García, J. L., Medina, C., and Frías, M. (2019). *Use of marble waste as a supplementary cementitious material in cement production.* Construction and Building Materials, 220, 245–255.

[17] Uysal, M., and Yilmaz, K. (2012*). Effect of mineral admixtures on properties of self-compacting concrete.* Construction and Building Materials, 27(1), 189–198.

[18] Kou, S. C., and Poon, C. S. (2016). *Sustainable use of marble waste in cementitious materials: A review.* Journal of Cleaner Production, 124, 327–343.

[19] ASTM International. (2023). *ASTM C150/C150M-23: Standard specification for Portland cement.* ASTM International. https://www.astm.org/c0150_c0150m-23.html

[20] European Committee for Standardization. (2011). *EN 197-1: Cement - Part 1: Composition, specifications, and conformity criteria for common cements.* CEN.

[21] Ezekiel, J. O., Akinrinde, E. A., and Bello, T. R. (2020). *Chemical characterization of Nigerian marble deposits for industrial applications*. Journal of Materials Science Research, 9(3), 45-57.

[22] Wang, L., and Zhang, Y. (2018). *Calcium-based fluxing agents in metallurgical processes: A review*. Metallurgical and Materials Transactions B, 49(6), 2903-2915.

[23] Gupta, R., and Chatterjee, A. (2021). *Ironmaking and steelmaking: Theory and practice*. Springer.

[24] Singh, P., Sharma, M., & Verma, R. (2019). *Advances in refractory technology for metallurgical furnaces*. Journal of Metallurgical Engineering, 15(2), 112-124.