Mining of Mineral Deposits
Volume 18 (2024), Issue 3, 18-24

MMD JOURNAL / MINING.IN.UA

https://doi.org/10.33271/mining18.03.018

Characterization and ceramic properties evaluation of Lombok clay

I Putu Angga Kristyawan[1*], Anak Agung Rai Indra Wardana[1], I Gusti Agung Suradharmika[1], Arifin Siagian[1], Made Asri Puspadewi[1], Ni Putu Muliawati[1], Komang Nelly Sundari[1], Totok Nugroho[1]

[1] *Research Center for Advanced Material, National Research and Innovation Agency (BRIN), South Tangerang, Indonesia*

**Corresponding author: e-mail iput006@brin.go.id*

Abstract

Purpose. This research aims to assess the characteristics of ceramics made from Lombok clay to optimize the quality of ceramic products in the Lombok region and surrounding areas.

Methods. Methods used to characterize Lombok clay include measuring its chemical composition, loss on ignition, plasticity level and conducting mineral analysis. Additionally, the influence of sintering temperature on clay properties and shrinkage is studied.

Findings. The main mineral component of Lombok clay is kaolin, which has a high level of plasticity and a water absorption rate of 7 ± 0.6%. The ceramic body produced from this clay is classified as semi-porcelain, making it suitable for medium-sized tableware manufactured using the rotating technique.

Originality. This research highlights the effect of sintering temperature on the mineral transformation of Lombok clay and provides valuable information on its optimal applications. It fills a gap in the literature by providing comprehensive data on clay properties and optimal processing conditions that have previously been underexplored.

Practical implications. Lombok clay is used predominantly by small-scale ceramic craftsmen in Lombok and Bali due to its relatively low market price. With the findings of this study, these craftsmen can enhance the quality of their products to semi-porcelain standards by adjusting the sintering temperature.

Keywords: *Lombok clay, ceramic characterization, semi-porcelain, sintering temperature, ceramic properties*

1. Introduction

Clay has been a vital material in ceramic production since prehistoric times [1]. Ceramic products made from clay encompass a wide range of items used in various industries and everyday life. These products include tableware, sanitary ware, tiles, pottery, refractories, electrical ceramics, as well as art and sculpture [2]-[5]. Ceramics are preferred because they are highly durable and resistant to wear and tear. They can withstand high temperatures, which makes them suitable for ovens and kilns. Additionally, ceramics are excellent electrical insulators and can be treated for aesthetic appeal by applying glazes and decorative elements [6], [7].

In 2019, the United States recorded 26 million tons of clay use estimated at $1.8 billion [8]. The high demand for clay in industry necessitates increased use of local clay sources to reduce dependence on imports [9]. In Indonesia, clay production has increased significantly to meet industrial needs, with a 60.81% increase in 2021 compared to the previous year [10]. Increased production implies a greater need for mining clay deposits. Clay deposits used as raw materials in the ceramic industry can be divided into several categories [11]: kaolins, white-firing plastic clays (ball clays), medium-low plasticity white-firing clays, red-firing plastic clays, and red-firing clays with carbonates. Kaolins, also known as China clay, is a specific type of clay mineral primarily composed of kaolinite. Kaolins are characterized by white color, fine particle size, and high plasticity, making them highly desirable for producing high-quality ceramic products. White-firing plastic clays, or ball clays, are highly valued in the ceramics industry for unique properties. These clays are known for their plasticity, which allows them to be easily shaped and molded when wet, and their ability to be fired to a white or light color. Medium-low plasticity white-firing clays are a type of clay which, as the name suggests, possesses moderate to low plasticity and is fired to a white or near-white color. Red-firing plastic clays are a type of clay that is highly plastic and fired to a red or reddish-brown color. Red-firing clays with carbonates are a type of clay that is fired to a red or reddish-brown color due to their iron oxide content with the addition of carbonate minerals such as calcite or dolomite. These clays differ in their firing behavior, which is influenced by the presence of carbonates.

Identifying areas for mining these clay deposits involves several stages [12]: selection of a prospecting area, explora-

Received: 2 May 2024. Accepted: 10 August 2024. Available online: 30 September 2024

Mining of Mineral Deposits. ISSN 2415-3443 (Online) | ISSN 2415-3435 (Print)

tion of potential mineral deposits (strategic prospecting), exploration and evaluation of mineral deposits (tactical prospecting), and final detailed exploration. Mining should be conducted in areas with clay suitable for the ceramic industry. Clay mining areas are at risk of environmental damage [13]-[15], such as deforestation and CO_2 emissions [16]. One effective method to address this is optimizing the use of clay from nearby areas (local clay) that have already been established effective as sources for the ceramic industry [9].

Small and medium industries near the clay sources tend to use local clay, because it reduces ceramic production costs. However, local clay use only undergoes strict quality control, leading to fluctuations in clay body quality. There are three basics of conventional clay body types [17]: porcelain, stoneware and earthenware. The main differences are in their firing temperatures, water absorption rates, strength, translucency, color, and application. Porcelain has the highest firing temperature range of 2400°F (1315°C) to 2600°F (1427°C) and the lowest water absorption rate (0-1%). It is also possible to make a clay body from a combination of clay and other materials, such as feldspar and quartz. To combine other material, the local clay needs to be characterized first. Clay characterization determines which ceramic products the clay is suitable for [1], [9], [18]-[21].

Essential characterizations include chemical composition, plasticity limit, shrinkage, water absorption, mineral content, and strength [18]-[21]. The chemical composition of clay analyzes the elemental and oxide composition of clay to understand its suitability for different ceramic products. The clay plasticity limit test measures the moisture content at which the clay begins to behave plastically, indicating its workability. Shrinkage characterizes the size reduction during drying and firing, which is crucial for dimensional accuracy of ceramic products. Water absorption determines the porosity of the sintered clay, affecting its strength and durability. Mineral content identifies the mineralogical composition to predict the clay behavior during processing and sintering. Strength assesses the fired clay mechanical properties to ensure that it meets the required standards for its intended use.

The general values for these characterizations vary depending on the clay type and its intended application. Typically, high-quality ceramic clays exhibit low impurity content, high plasticity, controlled shrinkage rates, moderate to low water absorption, and sufficient strength to withstand of use. By doing that, the optimization of local clay for the ceramic body can be achieved.

Indonesia has several regions with potential local clay, including Kalimantan [22], Yogyakarta [23], East Nusa Tenggara [24], and Bali [25], [26]. West Kalimantan Province has clay types such as kaolin and ball clays suitable for sanitary ware, tableware, and ceramic tiles. Ball clay from Kalimantan has a plasticity index above 25. The Kaolin deposits in West Kalimantan are reported to have a chemical composition of SiO_2 57.40%, Al_2O_3 27.46%, and Fe_2O_3 0.65%. The Kasongan area in Yogyakarta Province has red clay for pottery, as does the Buleleng area in Bali Province. The red clay from Buleleng is reported to have chemical composition of SiO_2 49.238%, Al_2O_3 21.065%, and Fe_2O_3 21.941%. One area that has not been well explored in previous studies is Lombok. In 2014, West Lombok was estimated to have clay reserves of 417.567 m^3 [27]. Previous research in Plambik village, Central Lombok, indicated kaolinite clay suitable for porcelain ceramic products [25]. Another area in Lombok, Mareje Village, has potential for clay suitable for the ceramic industry. However, no studies have been conducted regarding the characteristics of clay from Mareje village. This research aims to characterize and assess the effect of the sintering temperature of clay from Mareje village, West Lombok, to determine its suitability for use in the ceramic industry.

2. Methods

The material used in this research is one type of clay. This clay comes from the Mereje village area, Southwest Praya, Central Lombok Regency, West Nusa Tenggara. The clay is obtained by a simple process, namely settling and filtering. The filtered clay is then used in this characterization without adding other materials.

2.1. Characteristics of Lombok clay

The clay characterization included chemical analysis, loss of ignition, plasticity, mineral analysis, and morphological analysis. Chemical analysis of Lombok clay was carried out to determine the clay oxide content. The chemical composition of Lombok clay was analyzed using X-Ray Fluorescence Brand Panalytical Epsilon 3 XLE. Loss of ignition measurements are carried out according to ASTM C311 standards [28], [29]. The clay plasticity is measured to determine the clay plasticity level. The method used is the Atterberg method [30]. Analysis of Lombok clay minerals was carried out before and after sintering. Measurements were made using the X-Ray Powder Diffraction Panalytical. This mineral analysis is complemented by morphological analysis of ceramics using Field Emission Scanning Electron Microscopy (FESEM) with Energy Dispersive X-Ray Spectroscopy (EDS) ThermoScientific Quatro S to strengthen the analysis of the effect of sintering on the characteristics of Lombok clay ceramics.

2.2. Testing the properties of Lombok ceramics

Testing the characteristics of Lombok clay ceramics using rectangular test ceramic specimens with dimensions of 100×15×10 mm [30]. Measured ceramic characteristics include shrinkage, water absorption, and compressive strength. Linear shrinkage is measured according to ASTM C326-09 standards and calculated using Equation (1):

$$DS_{lc} = \frac{L_{tc0} - L_{tc1}}{L_{tc0}} \cdot 100\%, \tag{1}$$

where:

DS_{lc} – the Lombok clay drying shrinkage (%);

L_{tc0} – the initial length of test ceramics specimens (mm);

L_{tc1} – the length of test ceramics after drying (mm).

Lombok clay water absorption was measured using 10 test ceramic specimens according to ASTM C20-00 (2010) standards. Water absorption is calculated using Equation (2):

$$WA_{lc} = \frac{m_{tc0} - m_{tc1}}{m_{tc0}} \cdot 100\%, \tag{2}$$

where:

WA_{lc} – the Lombok clay water absorption (%);

m_{tc0} – the drying mass of test ceramics specimens (g);

m_{tc1} – the saturated mass of test ceramics specimens (g).

Flexural strength was measured before and after sintering test ceramics specimens to determine the mechanical strength using the three-point loading method [31].

For this research, a prototype of the ceramic product from Lombok clay was made to see its simplicity of use. The prototype of tableware products was made from cups using the manual shaping method (by hand). The prototype was dried for 4 days and sintered in a gas furnace to 900°C for 6 hours. After the first sintering, it is given colors and then sintered at 1185°C for 6 hours.

3. Results and discussion

3.1. Lombok clay chemical composition

The Lombok clay chemical analysis result is shown in Table 1. The two main compounds of this clay are Al_2O_3 and SiO_2, with their values 31.658 and 54.61% respectively. The other noticeable compounds are Fe_2O_3, ZnO, K_2O and TiO_2. The Al_2O_3 level in Lombok clay is higher compared to several areas in Indonesia [22]-[26]. Al_2O_3 plays an essential role in the structure of clay bodies, and the higher its content, the higher the strength and toughness of the product [32]. The SiO_2 content in Lombok clay reaches 54.61%, which is also higher compared to several other areas in Indonesia, such as Yogyakarta [23], Nusa Tenggara Timur [24] and Bali [25], [26]. The SiO_2 content in clay affects the melting temperature and tends to increase it [33]. Meanwhile, the Fe_2O_3 content, compared to Kalimantan clay [34], is higher, about 4.91%, which has an impact on the ceramic body color [30].

Table 1. Lombok clay chemical composition

Compound	Concentration (%)
Al_2O_3	31.658
SiO_2	54.610
P_2O_5	0.713
K_2O	1.658
CaO	1.223
TiO_2	1.252
Fe_2O_3	5.545
ZnO	2.688
ZrO_2	0.120
PbO	0.084

3.2. Lombok clay minerals and the effect of its sintering temperature

The Lombok clay mineralogical analysis and the influence of its sintering temperature are shown in Figure 1. Before sintering, clay contains minerals such as muscovite, quartz, kaolin and anatase. Quartz is shown as the dominant mineral in Lombok clay, which is similar to other clays [25], [26], [35]. The presence of muscovite can increase the plasticity and workability of clay [36]. Meanwhile, the presence of kaolin and anatase can increase the clay opacity and whiteness [37], making it more suitable for use in ceramics and pottery.

Clay sintering at 900°C shows that the mineral composition has not changed much compared to the period before sintering, which can still be found in minerals such as quartz, kaolin and anatase. Anatase is a metastable phase of titanium dioxide that can transform into rutile at higher temperatures. The presence of anatase in calcined Lombok clay is shown before sintering and at 900°C. The presence of anastase and rutile could be beneficial to the electrical ceramic characteristics [38]. After sintering at 1150°C, it shows the formation of mullite, rutile, cristobalite and quartz compounds. These minerals become increasingly evident when the clay is sintered at 1250°C.

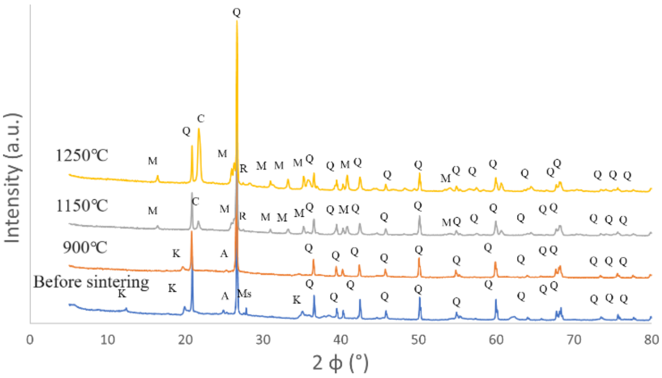

Figure 1. Lombok clay mineralogical analysis and the influence of its sintering temperature (Ms – muskovit; Q – quartz, K – kaolin, A – anatase, M – mullite, R – rutile, C – cristobalite)

Mullite is a common mineral in ceramic bodies, and its formation can affect mechanical strength, hardness, and toughness of ceramics [39]. Cristobalite is a high-temperature polymorph of silica that can be formed during sintering. When sintering Lombok clay it appears after 1150°C. The presence of cristobalite reduces the thermal ceramic expansion [40].

The FESEM image test results using the element data are shown in Figure 2. The results show that the higher the sintering temperature, the more the clay melts. It also shows Si/Al ratio increment from 1.62 before sintering to 2.70 after sintering at 1250°C. The increment of Si/Al ratio will affect the ceramic strength [41], which also confirms the presence of mullite in the Lombok clay sintering process [42]. The physical mass of stoneware ceramics generally contains a limited amount of silica, less than 20%. Its high content will make it easy for the greenware to retain its shape after drying. Apart from that, the ceramic body will be tough because the silica forms mullite minerals when it reacts with alumina that comes from kaolin. However, excess silica reduces the clay body plasticity level and causes a very high temperature of the ceramic body sintering [34].

3.3. Characteristics of Lombok clay ceramics

The results of plasticity measurements using the Atterberg method can be seen in Table 2. The plasticity index shows a value of 58.05%, and the liquid limit is 85.69%. This clay is classified as an inorganic clay category of high plasticity based on Casagrande plasticity chart [43]. Plasticity is crucial in processing clay-based materials, as it determines the pressure to shape a ceramic material into a specific form. In the context of clay minerals, plasticity refers to the ability of a material to be deformed repeatedly without breaking and to retain its shape after the applied force is removed. A clay-water system with high plasticity requires more force to deform and can deform more intensely without cracking. In contrast, a system with low plasticity deforms faster and breaks faster [44]. For application, the high plasticity clay can also be combined with less plastic clay to form a mixture with lower water content but remain plastic [45]. Plasticity is also an essential factor in reducing cost and environmental impact of ceramic production [46].

The Lombok clay ceramic characteristics are shown in Table 3. Based on water absorption, Lombok clay can be potentially used as a semi-porcelain type ceramic body where water absorption is in the range of 0.5-10% [47]. Semi-porcelain bodies are widely used for tableware and tile products [48].

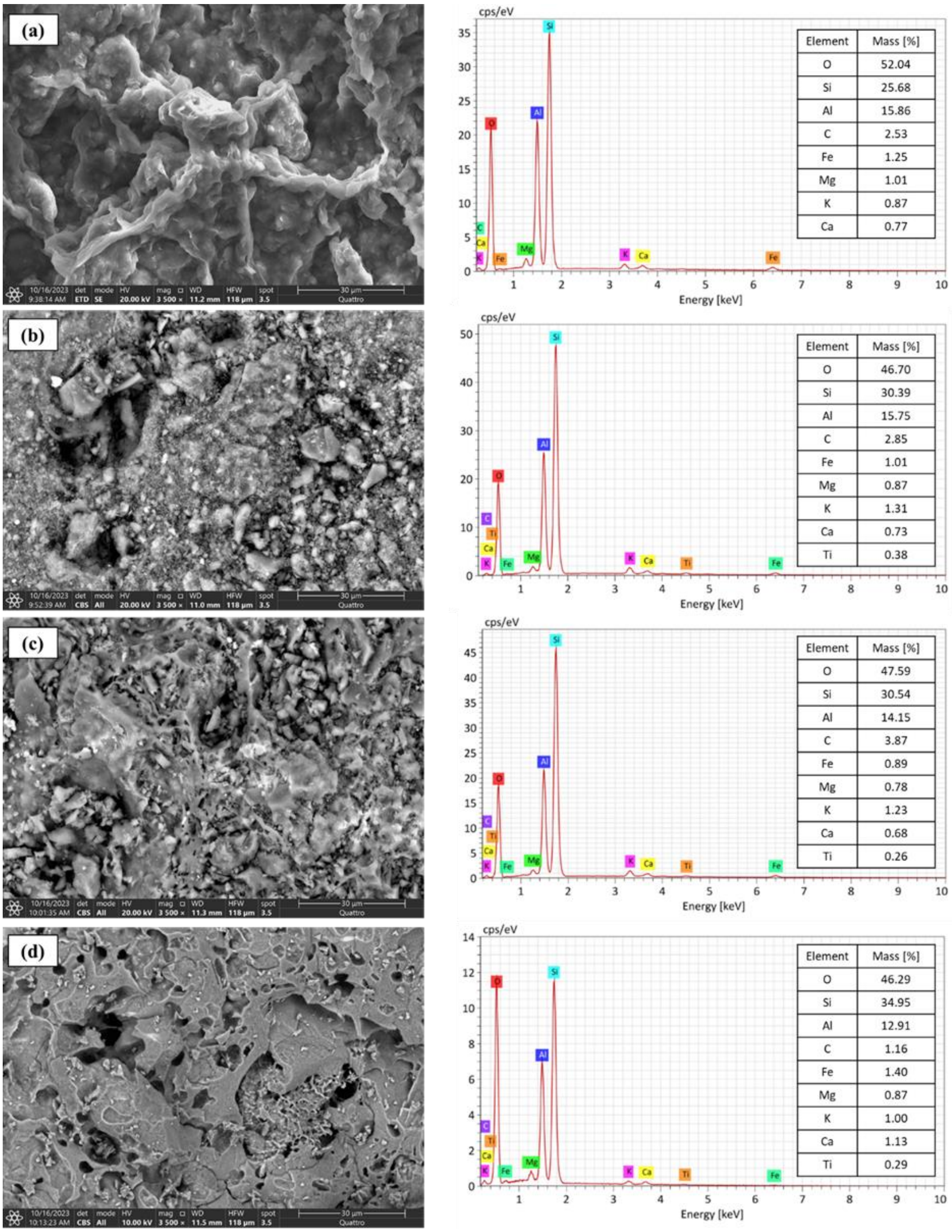

Figure 2. FESEM EDS test results: (a) before sintering; (b) sintering at 900°C; (c) sintering at 1150°C; (d) sintering at 1250°C

Table 2. Lombok clay plasticity value

Properties	Value (wt%)
Liquid Limit	85.69
Plastic Limit	27.64
Plasticity Index	58.05

Table 3. Lombok clay ceramic characteristics

Properties	Value	Unit
Dry shrinkage	20 ± 1.2	%
Firing shrinkage	16 ± 0.7	%
Total shrinkage	20 ± 0.7	%
Water absorption	7 ± 0.6	%
Compressive Strength	24.09 ± 5.86	N/mm^2
Modulus of rupture	232.59 ± 43.70	N/mm^2

The Indonesian ceramic industry also uses semi-porcelain bodies [49], which means that this clay can be commercialized. Then, the result of making tableware products using this clay was a cup. The cup is 9.44 cm in diameter and 7.74 cm high. The cup is made using the rotating technique, and the cup handle in particular is made using a sticking technique. The handle is made separately and then attached to the cup body. The product is then given black and white colors. During processing, a high shrinkage value affects the final result, where the cup lip appears curved and therefore asymmetrical.

3.4. Discussion and future perspectives

The discussion revolves around the characterization of Lombok clay, which has been found to have a high level of plasticity and a semi-porcelain nature.

The chemical composition, physical properties, and mineralogical content of the clay have been analyzed, revealing its potential for use in medium-sized tableware production using the rotating technique. However, further development is needed to reduce shrinkage. Reduction of shrinkage in tableware products made from Lombok clay or any other ceramic material can be achieved by several methods.

Clay body is usually made by combining several pieces of clay or material. Adjusting the proportion of clay, feldspar, quartz, and other minerals can help reduce shrinkage. For example, adding feldspar can reduce shrinkage by increasing the glass phase formation during firing [50]. Adding additives such as silica, alumina, or zirconia can help reduce shrinkage by increasing the material strength and reducing its thermal expansion [51]. Combination with other clays with lower shrinkage rates, such as porcelain or bone China, can help reduce shrinkage in tableware products [52]. Selecting a glaze with a lower thermal expansion coefficient can help reduce shrinkage and improve the product overall durability [53].

Molding greenware using pressing or extrusion techniques can help reduce shrinkage by applying uniform pressure and minimizing the formation of defects [54]. Designing molds with a tapered shape or using a non-stick coating can help reduce shrinkage by minimizing friction between the clay body and the mold [55]. Applying lubricants such as wax or oil to the mold or die can help reduce friction and minimize shrinkage during ejection [56].

Optimization of drying and sintering technique for the Lombok clay body. Controlling the moisture content in the clay body during processing can help minimize shrinkage. This can be achieved by adjusting the humidity, temperature, and drying time. Slow and gradual clay drying can help reduce shrinkage, minimizing the formation of cracks and defects [57]. Pre-sintering the clay body at a lower temperature can help reduce shrinkage by burning off organic materials and reducing the material sensitivity to thermal shock [58]. Optimizing the firing schedule, including temperature, soaking time, and cooling rate, can help reduce shrinkage. For example, a slower cooling rate can help reduce thermal shock and shrinkage [59]. Applying post-firing treatments such as annealing or tempering can help reduce shrinkage and improve the material strength and durability [60]. By implementing these methods, manufacturers can reduce shrinkage in tableware products made from Lombok clay or other ceramic materials, resulting in higher quality and more consistent products.

The future prospects of this research is in potential applications of Lombok clay in the ceramics industry. With further refinement and development, this clay can be used to produce high-quality tableware and other ceramic products. Additionally, the research could lead to the discovery of new uses for Lombok clay, such as the production of refractory materials, paper, or other industrial applications. The research findings could also contribute to the development of more sustainable and environmentally friendly ceramic production methods.

4. Conclusions

The chemical composition of Lombok clay, primarily consisting of 31.658% Al_2O_3 and 54.61% SiO_2, indicates its potential for producing robust and high-temperature resistant ceramic products. The significant Fe_2O_3 content (5.545%) also influences the color of the final ceramic product. Mineralogical analysis shows that Lombok clay before sintering contains muscovite, quartz, kaolin, and anatase, with quartz as the dominant mineral. These minerals improve the plasticity, workability, opacity, and whiteness of clay, making it suitable for use in ceramics and pottery. Sintering at different temperatures reveals changes in mineral composition, forming mullite, rutile, and cristobalite at higher temperatures (1150 and 1250°C). These minerals enhance the mechanical strength, hardness, toughness, and thermal expansion properties of ceramics.

Lombok clay demonstrates high plasticity, with a plasticity index of 58.05% and a liquid limit of 85.69%, categorizing it as highly plastic inorganic clay. This high plasticity is advantageous in the production of ceramics, allowing extensive deformation without cracking. The potential of Lombok clay for semi-porcelain ceramic bodies is highlighted by its water absorption rate of $7 \pm 0.6\%$, aligning with the standards for tableware and tile products. However, high shrinkage values (total shrinkage $20 \pm 0.7\%$) pose challenges in maintaining the shape and symmetry of the final products. The shrinkage problem can be addressed by several methods, including adjusting the clay body composition with feldspar, silica, alumina, or zirconia and optimizing the molding and firing techniques. These adjustments can help reduce shrinkage, improve material strength, and enhance the overall quality and durability of the ceramic products.

Future research should focus on improving Lombok clay to minimize shrinkage and explore its applications in the production of high-quality tableware, refractory materials, paper, and other industrial products. The research findings also contribute to the development of more sustainable and environmentally friendly ceramic production methods, opening new opportunities for the commercial use of Lombok clay.

Author contributions

Conceptualization: AARIW; Data curation: MAP, NPM; Formal analysis: IPAK; Funding acquisition: IPAK; Investigation: MAP, NPM; Methodology: IPAK, KNS, TN; Project administration: IGAS; Resources: AARIW; Supervision: TN; Validation: KNS; Visualization: IPAK; Writing – original draft: IPAK, IGAS, AS, TN; Writing – review & editing: IPAK, IGAS, AS, TN. All authors have read and agreed to the published version of the manuscript.

Funding

This research received no external funding.

Acknowledgements

The authors acknowledge the facilities, scientific and technical support from Mining Materials Laboratory Lampung, National Research and Innovation Agency through E-Layanan Sains, Badan Riset dan Inovasi Nasional.

Conflicts of interests

The authors declare no conflict of interest.

Data availability statement

The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author.

References

[1] Marques, R., Jorge, A., Franco, D., Dias, M.I., & Prudêncio, M.I. (2010). Clay resources in the Nelas region (Beira Alta), Portugal. A contribution to the characterization of potential raw materials for prehistoric ceramic production. *Clay Minerals*, *45*(3), 353-370. https://doi.org/10.1180/claymin.2010.045.3.353

[2] González, A.S., Valera, T.S., & Toffoli, S.M. (2014). Design of a ceramic slip for electrical porcelain insulators, using clay dispersed in a ball mill. *Materials Science Forum*, *805*, 475-479. https://doi.org/10.4028/www.scientific.net/MSF.805.475

[3] Boussak, H., Chemani, H., & Serier, A. (2015). Characterization of porcelain tableware formulation containing bentonite clay. *International Journal of Physical Sciences*, *10*(1), 38-45. https://doi.org/10.5897/ijps2014.4218

[4] Mikhalev, V.V., & Vlasov, A.S. (2007). Properties of clays for manufacturing sanitary ware. *Glass and Ceramics*, *64*, 78-81. https://doi.org/10.1007/s10717-007-0019-2

[5] Sawadogo, M., Seynou, M., Zerbo, L., Sorgho, B., Laure Lecomte-Nana, G., Blanchart, P., & Ouédraogo, R. (2020). Formulation of clay refractory bricks: influence of the nature of chamotte and the alumina content in the clay. *Advances in Materials*, *9*(4), 59-67. https://doi.org/10.11648/j.am.20200904.11

[6] Subedi, M.M. (2013). Ceramics and its importance. *Himalayan Physics*, *4*(4), 80-82. https://doi.org/10.3126/hj.v4i0.9433

[7] Fang, M., & Chen, H. (2020). Advantages and disadvantages of ceramic materials in environmental art. *IOP Conference Series: Materials Science and Engineering*, *782*(2), 022030. https://doi.org/10.1088/1757-899X/782/2/022030

[8] United States Geological Survey. (2020). *Mineral commodity summaries 2020: Clays*. Available at: https://pubs.usgs.gov/periodicals/mcs2020/mcs2020-clays.pdf

[9] Akanda, M.M., Mallik, A., Bin Karim, A., & Mintu Ali, M. (2019). Locally available clays of bangladesh as a replacement of imported clays for ceramic industries. *Advanced Materials Letters*, *10*(11), 839-843. https://doi.org/10.5185/amlett.2019.0022

[10] BPS-Statistics Indonesia (n.d.). *Volume of mining production of mineral commodities (m3) 2019-2021 (in Bahasa)*. Retrieved from: https://www.bps.go.id/id/query-builder

[11] Dondi, M., & Gian Paolo, B. (2021). Basic guidelines for prospecting and technological assessment of clays for the ceramic industry, Part 1. *InterCeram: International Ceramic Review*, *70*(4), 36-46. https://doi.org/10.1007/s42411-021-0472-x

[12] Dondi, M., & Gian Paolo, B. (2022). Basic Guidelines for Prospecting and Technological Assessment of Clays for the Ceramic Industry, Part 2. *InterCeram: International Ceramic Review*, *71*(1), 28-37. https://doi.org/10.1007/s42411-022-0484-1

[13] Akanwa, A.O., & Joe-Ikechebelu, N.N. (2022). Sustainable natural resources exploitation: Clay/sand mining on diminishing greener security and increased climate risks in Nigeria. *Natural Resources Conservation and Advances for Sustainability*, 545-562. https://doi.org/10.1016/B978-0-12-822976-7.00018-1

[14] Ramadhan, N.F., Gunawan, T., & Adji, T.N. (2020). Environmental damage assessment due to traditional mining on local scale in the Wungkal Hills, Yogyakarta-Indonesia. *Journal of Degraded and Mining Lands Management*, *7*(2), 1995-2000. https://doi.org/10.15243/jdmlm.2020.072.1995

[15] Arunashantha, S., & Bandara, S.M.R.S. (2020). The environmental impact of the clay industry in Sri Lanka: With special reference to Dankotuwa Divisional Secretariat Division (DSD). *International Journal of Scientific and Research Publications*, *10*(7), 92-96. https://doi.org/10.29322/ijsrp.10.07.2020.p10311

[16] Furszyfer Del Rio, D.D., Sovacool, B.K., Foley, A.M., Griffiths, S., Bazilian, M., Kim, J., & Rooney, D. (2022). Decarbonizing the ceramics industry: A systematic and critical review of policy options, developments and sociotechnical systems. *Renewable and Sustainable Energy Reviews*, *157*, 112081. https://doi.org/10.1016/j.rser.2022.112081

[17] Zawrah, M.F., Taha, M.A., & Youness, R.A. (2024). Advanced ceramics: Stages of development. *Advanced Ceramics. Advances in Material Research and Technology*, 1-46. https://doi.org/10.1007/978-3-031-43918-6_1

[18] Milošević, M., Logar, M., Kaluderović, L., & Jelić, I. (2017). Characterization of clays from Slatina (Ub, Serbia) for potential uses in the ceramic industry. *Energy Procedia*, *125*, 650-655. https://doi.org/10.1016/j.egypro.2017.08.270

[19] Manjate, V.A., Issufo, Z., & Magenge, A.L. (2020). Evaluation of clay soils from Manjacazi district (Mozambique) as potential raw material for the ceramic industry. *Heliyon*, *6*(10), e05189. https://doi.org/10.1016/j.heliyon.2020.e05189

[20] Pardo, F., Jordan, M.M., & Montero, M.A. (2018). Ceramic behaviour of clays in Central Chile. *Applied Clay Science*, *157*, 158-164. https://doi.org/10.1016/j.clay.2018.02.044

[21] Ben Salah, I., Sdiri, A., Ben M'barek Jemai, M., & Boughdiri, M. (2018). Potential use of the lower cretaceous clay (Kef area, North-western Tunisia) as raw material to supply ceramic industry. *Applied Clay Science*, *161*, 151-162. https://doi.org/10.1016/j.clay.2018.04.015

[22] Subari, Wenas, R.I.F., & Suripto, S. (2008). Industrial minerals in West Kalimantan and their utilization for ceramic products. *Indonesian Mining Journal*, *11*(3), 27-37. https://doi.org/10.30556/imj.Vol11.No3.2008.583

[23] Winarno, T. (2016). Comparison of the characteristics of Kasongan and Godean clays as raw materials for the Kasongan pottery industry (in Bahasa). *Teknik*, *37*(1), 41-46. https://doi.org/10.14710/teknik.v37i1.10087

[24] Bambali, I.J., & Rumbino, Y. (2021). Characteristics of clay and beach sand as raw materials for Gerabah in Ampera village, Kecamatan Alor Baratlaut Alor district, Nusa Tenggara Timur (in Bahasa). *Journal Teknologi*, *15*(1), 34-42.

[25] Nugroho, T., Prajoko, B., Suryawan, I.G., & Sukadana, W. (2023). Analysis of clay mineral transformation in Plambik village, Central Lombok using x-ray diffraction and scanning electron microscope methods. *Journal of Physics and Its Applications*, *6*(1), 7-10. https://doi.org/10.14710/jpa.v6i1.19011

[26] Sundari, K.N., Subari, & Erlangga, B.D. (2022). Characterization of Buleleng clay and improvement of its ceramic properties. *Mining of Mineral Deposits*, *16*(4), 29-33. https://doi.org/10.33271/mining16.04.029

[27] Badan Pusat Statistik. (2015). *Number of mineral resources by kind of mineral 2014*. Retrieved from: https://lombokbaratkab.bps.go.id

[28] Akbar, T., & Hendratno. (2022). Characteristics of Parit Malintang clay as a local wealth for raw material for ceramic crafts (in Bahasa). *Journal of Craft*, *2*(1), 24-30. https://doi.org/10.26887/relief.v2i1.2591

[29] Putri, S.E., & Pratiwi, D.E. (2017). Analysis of mineral in South Sulawesi natural clay as basic material of ceramic synthesis (in Bahasa). *Journal Chemical*, *18*(1), 35-38. https://doi.org/10.35580/chemica.v18i1.4668

[30] Gol, F., Saritas, Z.G., Cıbuk, S., Ture, C., Kacar, E., Yilmaz, A., Arslan, M., & Sen, F. (2022). Coloring effect of iron oxide content on ceramic glazes and their comparison with the similar waste containing materials. *Ceramics International*, *48*(2), 2241-2249. https://doi.org/10.1016/J.CERAMINT.2021.10.001

[31] Hou, C., Jin, X., Zhao, L., Li, P., & Fan, X. (2022). Analysis of tensile strength and fracture toughness of ZrB_2-SiC ceramic from three-point bending samples with edge cracks. *Ceramics International*, *48*(20), 30078-30085. https://doi.org/10.1016/j.ceramint.2022.06.278

[32] Wang, W., Chen, J., Sun, X., Sun, G., Liang, Y., & Bi, J. (2022). Influence of additives on microstructure and mechanical properties of alumina ceramics. *Materials*, *15*(8), 1-11. https://doi.org/10.3390/ma15082956

[33] Casasola, R., Rincón, J.M., & Romero, M. (2012). Glass-ceramic glazes for ceramic tiles: A review. *Journal of Materials Science*, *47*(2), 553-582. https://doi.org/10.1007/s10853-011-5981-y

[34] Subari. (2014). The use feldspathic sandstone and claystone for ornamental ceramics. *Journal Teknologi Mineral Dan Batubara*, *10*(3), 155-164. https://doi.org/10.30556/jtmb.Vol10.No3.2014.731

[35] Balde, M.Y., Njiomou Djangang, C., Bah, A., Blanchart, P., & Njopwouo, D. (2021). Effect of physicochemical characteristics on the use of clays from Kindia (Guinea) in ceramic compositions. *International Journal of Applied Ceramic Technology*, *18*(3), 1033-1042. https://doi.org/10.1111/ijac.13669

[36] Delle Piane, C., Wilson, C. J. L., & Burlini, L. (2009). Dilatant plasticity in high-strain experiments on calcite-muscovite aggregates. *Journal of Structural Geology*, *31*(10), 1084-1099. https://doi.org/10.1016/j.jsg.2009.03.005

[37] Buyondo, K.A., Kasedde, H., & Kirabira, J.B. (2022). A comprehensive review on kaolin as pigment for paint and coating: Recent trends of chemical-based paints, their environmental impacts and regulation. *Case Studies in Chemical and Environmental Engineering*, *6*, 100244. https://doi.org/10.1016/j.cscee.2022.100244

[38] Kirstein, K., Reichmann, K., Preis, W., & Mitsche, S. (2011). Effect of commercial anatase-TiO_2 raw materials on the electrical characteristics of ceramics with positive temperature coefficient of resistivity. *Journal of the European Ceramic Society*, *31*(13), 2339-2349. https://doi.org/10.1016/j.jeurceramsoc.2011.05.028

[39] Aksel, C. (2003). The effect of mullite on the mechanical properties and thermal shock behaviour of alumina-mullite refractory materials. *Ceramics International*, *29*(2), 183-188. https://doi.org/10.1016/S0272-8842(02)00103-7

[40] Zawrah, M.F., & Hamzawy, E.M.A. (2002). Effect of cristobalite formation on sinter ability, microstructure and properties of glass/ceramic composites. *Ceramics International*, *28*(2), 123-130. https://doi.org/10.1016/S0272-8842(01)00067-0

[41] Lahoti, M., Wong, K.K., Yang, E.-H., & Tan, K.H. (2018). Effects of Si/Al molar ratio on strength endurance and volume stability of metakaolin geopolymers subject to elevated temperature. *Ceramics International*, *44*(5), 5726-5734. https://doi.org/10.1016/j.ceramint.2017.12.226

[42] Schneider, H., Schreuer, J., & Hildmann, B. (2008). Structure and properties of mullite – A review. *Journal of the European Ceramic Society*, *28*(2), 329-344. https://doi.org/10.1016/j.jeurceramsoc.2007.03.017

[43] Casagrande, A. (1948). Classification and identification of soils. *Transactions of the American Society of Civil Engineers*, *113*(1). https://doi.org/10.1061/TACEAT.0006109

[44] Andrade, F.A., Al-Qureshi, H.A., & Hotza, D. (2011). Measuring the plasticity of clays: A review. *Applied Clay Science*, *51*(1), 1-7. https://doi.org/10.1016/j.clay.2010.10.028

[45] Barnes, G.E. (2018). Workability of clay mixtures. *Applied Clay Science*, *153*, 107-112. https://doi.org/10.1016/j.clay.2017.12.006

[46] Nandi, V. de S., Zaccaron, A., Raupp-Pereira, F., Arcaro, S., Bernardin, A.M., & Montedo, O.R.K. (2023). Plastic behaviour of clay materials for the manufacture of fast-drying red ceramics. *Clay Minerals*, *58*(1), 26-37. https://doi.org/DOI:10.1180/clm.2023.9

[47] Badan Standardizes Nasional. (2008). *SNI 7275:2008: Glazed ceramics – Tableware – Eating and drinking utensils*. Indonesian National Standardization Agency.

[48] Toplicic-Curcic, G., Momcilovic-Petronijevic, A., & Curcic, A. (2018). Architecture and ceramic materials, development through time: Ceramic tiles and ceramic roof tiles. *Facta Universitatis – Series: Architecture and Civil Engineering*, *16*(2), 315-327. https://doi.org/10.2298/fuace200521011t

[49] Alvira, R.C. (2022). Digital marketing application to increase sales turnover of naruna handmade ceramic products. *Inaque: Journal of Industrial and Quality Engineering*, *10*(1), 37-55. https://doi.org/10.34010/iqe.v10i1.6323

[50] Ngun, B.K., Mohamad, H., Katsumata, K., Okada, K., & Ahmad, Z.A. (2014). Using design of mixture experiments to optimize triaxial ceramic tile compositions incorporating Cambodian clays. *Applied Clay Science*, *87*, 97-107. https://doi.org/https://doi.org/10.1016/j.clay.2013.11.037

[51] Li, H., Liu, Y., Liu, Y., Zeng, Q., & Liang, J. (2021). Silica strengthened alumina ceramic cores prepared by 3D printing. *Journal of the European Ceramic Society*, *41*(4), 2938-2947. https://doi.org/10.1016/j.jeurceramsoc.2020.11.050

[52] Toludare, T.S., Owoeye, S.S., Kenneth-Emehige, A., & Isinkaye, O.E. (2019). Microstructure evolution and physico-mechanical properties of bone China porcelain compositions using two selected kaolinite clays from Nigeria. *Scientific African*, *3*, e00066. https://doi.org/10.1016/j.sciaf.2019.e00066

[53] Reinosa, J.J., Rubio-Marcos, F., Solera, E., Bengochea, M.A., & Fernández, J.F. (2010). Sintering behaviour of nanostructured glass-ceramic glazes. *Ceramics International*, *36*(6), 1845-1850. https://doi.org/10.1016/j.ceramint.2010.03.029

[54] Zhang, Y., Tan, Y., Sun, R., & Zhang, W. (2023). Preparation of ceramic membranes and their application in wastewater and water treatment. *Water*, *15*(19), 3344. https://doi.org/10.3390/w15193344

[55] Charmeau, J.-Y., Chailly, M., Gilbert, V., & Béreaux, Y. (2008). Influence of mold surface coatings in injection molding. Application to the ejection stage. *International Journal of Material Forming*, *1*(1), 699-702. https://doi.org/10.1007/s12289-008-0311-x

[56] Enneti, R.K., Lusin, A., Kumar, S., German, R.M., & Atre, S.V. (2013). Effects of lubricant on green strength, compressibility and ejection of parts in die compaction process. *Powder Technology*, *233*, 22-29. https://doi.org/10.1016/j.powtec.2012.08.033

[57] Oummadi, S., Nait-Ali, B., Alzina, A., Paya, M.-C., Gaillard, J.-M., & Smith, D.S. (2020). Optical method for evaluation of shrinkage in two dimensions during drying of ceramic green bodies. *Open Ceramics*, *2*, 100016. https://doi.org/10.1016/j.oceram.2020.100016

[58] Anjum, F., Ghaffar, A., Jamil, Y., & Majeed, M.I. (2019). Effect of sintering temperature on mechanical and thermophysical properties of biowaste-added fired clay bricks. *Journal of Material Cycles and Waste Management*, *21*(3), 503-524. https://doi.org/10.1007/s10163-018-0810-x

[59] Bragança, S.R., & Bergmann, C.P. (2004). Traditional and glass powder porcelain: Technical and microstructure analysis. *Journal of the European Ceramic Society*, *24*(8), 2383-2388. https://doi.org/10.1016/j.jeurceramsoc.2003.08.003

[60] Casasola, R., Rincón, J.M., & Romero, M. (2012). Glass-ceramic glazes for ceramic tiles: A review. *Journal of Materials Science*, *47*(2), 553-582. https://doi.org/10.1007/s10853-011-5981-y

Характеристика та оцінка керамічних властивостей глини з острова Ломбокс

І.П.А. Крістьяван, А.А.Р.І. Вардана, І.Г.А. Сурадхарміка, А. Сіагян,

М.А. Пуспадеві, Н.П. Муліаваті, К.Н. Сундарі, Т. Нугрохо

Мета. Оцінка характеристик і властивостей кераміки, виготовленої з глини острова Ломбок, для оптимізації якості керамічних виробів у регіоні Ломбок та прилеглих районах.

Методика. Методи, що використовуються для характеристики ломбокської глини, включають вимірювання її хімічного складу, втрат при прожарюванні, рівня пластичності та проведення аналізу мінералів. Крім того, вивчається вплив температури спікання на властивості глини та її усадку.

Результати. Визначено хімічний склад ломбокської глини, який вказує на її значний потенціал для виробництва міцних і стійких до високих температур керамічних виробів. Встановлено, що основним мінеральним компонентом глини з острова Ломбок є каолін, який володіє високим рівнем пластичності та водопоглинання 7 ± 0.6%. Виявлено зміни в мінеральному складі при спіканні глини в умовах різних температур, внаслідок чого утворюються муліт, рутил і кристобаліт при більш високих температурах (1150 і 1250°C), що підвищує механічну міцність, твердість, ударну в'язкість і властивості кераміки в результаті температурного розширення. Керамічний корпус, виготовлений з цієї глини, класифікується як напівпорцеляновий, що робить його придатним для виробництва посуду середнього розміру, створеного за допомогою техніки обертання. Запропоновано рекомендації для мінімізації величини усадки керамічних виробів.

Наукова новизна. У цьому дослідженні наголошується на впливі температури спікання на мінеральне перетворення ломбокської глини та надається цінна інформація щодо її оптимального застосування. Дослідження заповнює прогалину в існуючих на сьогодні літературних джерелах, надаючи вичерпні дані щодо властивостей глини та оптимальних умов обробки, які раніше були недостатньо вивчені.

Практична значимість. Ломбокська глина використовується, переважно, дрібними майстрами керамічної галузі Ломбока та Балі через її відносно низьку ринкову ціну. Використовуючи результати цього дослідження, майстри можуть покращити якість своїх виробів до стандартів напівпорцеляни, регулюючи температуру спікання.

Ключові слова: *ломбокська глина, характеристика кераміки, напівпорцеляна, температура спікання, властивості кераміки*

Publisher's note