Mining of Mineral Deposits
Volume 16 (2022), Issue 4, 29-33

MMD JOURNAL / MINING.IN.UA

https://doi.org/10.33271/mining16.04.029

Characterization of Buleleng clay and improvement of its ceramic properties

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Abstract

Purpose. The research focuses on the improvement of local clay-based ceramic pottery bodies from Alas Angker in Buleleng Regency in Bali. The main purpose is to utilize the clay which meets the standards of ceramics such as smooth and hard earthenware, especially to reduce its water absorption property.

Methods. Firstly, the clay is analyzed for its physical and chemical composition. Two ceramic body formulations are made using the clay with the BWNAA1 and BWNAA2 codes. The specimens are measured in terms of clay ceramics properties including plasticity, dry shrinkage, firing shrinkage and water absorption. The cracked ceramic products are also analyzed for a comparison.

Findings. The ceramic properties show similar results, except for the water absorption percentage. The BWNAA2 code formulation has lower water absorption rate by 10.8% and meets the requirements for the type of smooth and hard earthenware body in compliance with the national standard SNI:7275-2018. The water absorption rate is about half of the existing products, which is effective in avoiding the problem of cracks.

Originality. Comparison of the existing ceramic products and specimens made in this study shows a significant difference in water absorption and crack growth. Adding a certain amount of kaolin, feldspar, ball clay and quartz sand has significantly reduced the water absorption rate of ceramic bodies.

Practical implications. This research can be a potential solution to increase the quality of ceramic pottery products in the vicinity of Buleleng Regency which use the clay of this kind.

Keywords: *Buleleng clay, conventional ceramic, ceramic body, water absorption*

1. Introduction

The development of conventional ceramics is closely linked to its source of raw materials. The raw materials have been obtained from minerals on Earth and by processing some ceramic residues [1]. Some research on ceramic bodies has also been done with variations ingredients such as feldspar [2], [3], volcanic ash [4], kaolin [5] and local clay [6].

Clay is one of the important materials for the manufacture of traditional ceramics. Clay has plasticity properties when exposed to water and can become a hard solid material after firing at high temperature [7]-[9], resulting in clay being widely used in the field of ceramics. Furthermore, the purity and type of clay minerals greatly determine the quality of the resulting ceramic products [10].

The place for producing traditional clay-based ceramics is often located close to the source of the raw materials. For instance, the clay used in the pottery center in Bayat, Klaten, has been examined for its characteristics and origin [11]. It is shown that minerals of quartz and albite predominate in the clays of the Bayat area. However, the study does not analyze the ceramic properties of the clay source.

The production of traditional clay-based ceramics generally ends with exposure to high temperatures, which affects its physical and mechanical properties. After the firing process of ceramic materials, a reddish-brown color can normally occur in a clay-based body due the presence of hematite (Fe_2O_3) [12]. In addition, specimens with a high content of plastic clay are more prone to cracking, followed by significant mass loss during firing [13]. Cracks can also be observed when samples are subjected to fast drying process and experience uneven drying in the ceramic body [14]. Moreover, it is reported that cracks can be identified by the formation of a glassy phase after exposure to the firing temperature [15]. So, an understanding of the clay properties is essential to maintain its durability and use in the ceramic industry.

In Bali, the pottery craftsmen at the Banyuning Pottery Center have been using local clay for manufacturing traditional ceramics since ancient times [16]. Currently, they use clay from Alas Angker Village in Buleleng Regency for crafting fine earthenware type of ceramics. However, research on the clay characteristics and its ceramic properties has not been conducted. The clay quarry in Alas Angker Village, Buleleng Regency, Bali can be seen in Figure 1.

It has also been found that the pottery products based on this clay are prone to cracking, which can deteriorate their strength and performance.

Received: 16 June 2022. Accepted: 17 October 2022. Available online: 30 December 2022

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

Figure 1. Clay quarry in Alas Angker Village, Buleleng

A photograph showing some cracks in the pottery can be seen in Figure 2. This is probably due to the inappropriate balance of raw materials used in the mixture. In addition, the low mechanical strength of clay-based ceramics can be affected by high water absorption and insufficient firing temperature [17]. Therefore, in order to maintain the continuity of conventional ceramic production in the Bali area, in particular, technical research is required on the use of clay as ceramic raw material and its ceramic properties. In this study, the earthenware composition is developed to enhance appropriate ceramic properties, while the cracked pottery products are measured for their water absorption for comparison.

Figure 2. Problem of cracking pottery products

A preliminary study on the characteristics of the clay for ceramic purposes was conducted using a high-ferric clay source from northeastern Morocco, which contains mostly smectite clay, which has a high humidity content and problems with swelling during forming and drying [18]. In conclusion, a recommendation was made to include other less plastic minerals with in the clay to create appropriate mixture for ceramic materials. It has also been suggested to add sands or other degreasing agents to prevent cracks in the clay body after firing [12]. Thus, this research is conducted with the purpose of improving the properties of ceramics made of clay from Buleleng area so that the destruction caused by cracking could be prevented. The main practical parameter used to reduce the risk of cracking in specimens is to control the water absorption rate of no more than 15%, in compliance with the local standard SNI:7275-2018 [19], by adding other ingredients to the mixture. Further, this improvement may have the potential to improve the quality of conventional ceramic products and subsequently promote sustainability of local ceramic crafting activity.

2. Materials and method

In this research, clay from Alas Angker, Buleleng, Bali, Indonesia was characterized and used for manufacturing earthenware specimens. Clay samples were taken directly from the quarry. Meanwhile, other materials for enhancing the mixture have been prepared from other areas. During the experiment, the value of water absorption of the existing products from the craftsmen was compared with laboratory experimental specimens.

2.1. Clay characterization

The characterization involves an analysis of the physical and chemical properties of the clay. The physical analysis begins with measuring the grain size distribution by particle size analysis. The chemical composition of the clay is determined by X-ray fluorescence (XRF) analysis using Omnian ED-XRF PANalytical Epsilon 3 XLE device. Then, using X-ray diffraction (XRD), the mineral content in the clay is determined. The XRD apparatus used in this study is a Bruker D8 Advance with a LynxEye XE-T detector and Cu-K alfa radiation. The XRD graph is matched with the ICDD database to reveal its mineral content performed using EVA software. Then, the plasticity properties are determined using the Atterberg limits and a simple rolling method.

In addition, the plasticity behavior is determined based on the plasticity index (PI) using the Atterberg method. PI is a measure of plasticity, which is the difference between the liquid limit (LL) and the plasticity limit (PL). The measurement are conducted according to the method described in the work of Cannon and Wynn, 1999 [20].

2.2. Manufacturing of ceramic specimens

The Buleleng clay is the main component for creating the specimens, accounting for 50 wt% of the mixture. The clay from the quarry is pulverized into smaller particles that pass through an 80 mesh sieve. Meanwhile, other materials consisting of kaolin, feldspar, ball clay and quartz sand are used to enhance the ceramic properties. The ingredients used in the experiment are prepared in two compositions, as shown in Table 1.

Table 1. Composition of ceramic specimens (in wt%)

Raw materials	BWNAA1	BWNAA2
Clay	50	50
Kaolin	5	5
Feldspar	25	30
Ball clay	5	5
Quartz	15	10

After weighing the ingredients, they are mixed in a dry condition. Water is gradually added to the composition until it reaches its plasticity. The mixtures are aged for 24 h to stimulate workability of the ceramic body prior to forming it into bulk specimens with 100×15×10 mm dimension. The plasticity property is then examined in a simple manner, by shaping a circle, connecting each end of the test object in the form of a cylinder 1cm in diameter and 12 cm long. In the absence of cracks, the mixture can be considered as a plastic material for ceramic purposes.

2.3. Measuring ceramic properties

Each ceramic mixture was made from ten specimens for dry shrinkage, firing shrinkage and water absorption test. Firstly, the dry shrinkage is determined by comparing the dimension before (a) and after the drying process for 48 h at room temperature (k). The percentage of dry shrinkage (DS) is calculated using the following Formula:

$$DS = \frac{(a-k)}{a} \cdot 100\% . \tag{1}$$

Secondly, the firing shrinkage test, a firing temperature at 1150ºC for 8 h is applied. The difference in length is measured prior to (k) and after firing (b). In addition to this, the total shrinkage is also calculated based on these parameters. Then, the equations used for calculating firing shrinkage (FS) and total shrinkage (TS) are as follow:

$$FS = \frac{(k-b)}{k} \cdot 100\% ; \tag{2}$$

$$TS = \frac{(a-b)}{a} \cdot 100\% . \tag{3}$$

Furthermore, the fired specimens are measured by weight (D) and are immersed in fresh water for 24 h. The specimens are subsequently weighed and marked as saturated weight (S). The water absorption (WA) is calculated by Formula 4:

$$WA = \frac{(S-D)}{D} \cdot 100\% . \tag{4}$$

In addition, cracked pottery products, collected from home ceramic industry are measured for water absorption rate. These data are subsequently used for a comparison with developing earthenware specimens.

3. Results and discussion

The particle size analysis has revealed that natural clay consists of a significant proportion of larger particles ranging in size from 100 to 500 μm (Fig. 2). This is due to the lack of pre-treatment prior to measurement, which means that smaller particles cannot be completely dispersed. Thus, milling and sieving are necessary to achieve the desired grain size for further use.

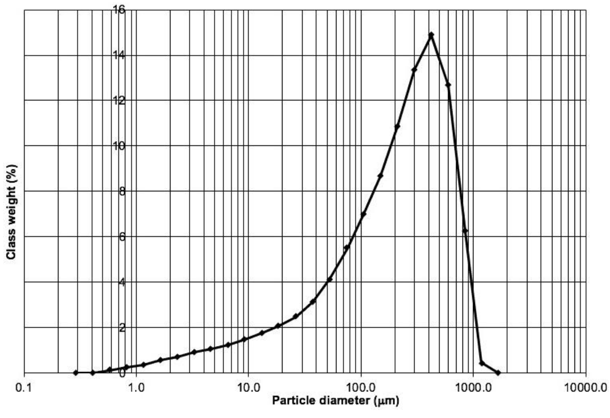


Figure 2. Particle size distribution of the natural clay

The clay composition, based on X-ray fluorescence (XRF) analysis, mainly consists of SiO_2, Al_2O_3 and Fe_2O_3 (Table 2).

Table 2. X-Ray fluorescence analysis of clay from Buleleng

Oxides compound	Concentration, %
Al_2O_3	21.065
SiO_2	49.238
P_2O_5	0.787
K_2O	0.798
CaO	3.398
TiO_2	1.801
MnO	0.495
Fe_2O_3	21.941

The amount of Al_2O_3, which makes a significant contribution to imparting plasticity properties to the clay body, is relatively low and amounted to 21.065%. The Fe_2O_3 compound at 21.941% is quite significant for giving a rusty red color to the clay sample. The X-ray diffraction (XRD) analysis has revealed the minerals anorthite and albite (Fig. 3). The typical clay phase is also seen in the form of humps on the graph. The presence of anorthite here can play a pivotal role in maintaining the strength and thermal resistance of conventional ceramic products [21]. Further, the intermingling albite-anorthite mineral can be considered as plagioclase. This characteristic is somewhat similar to some clays, containing plagioclase mineral, which is used in the Bayat ceramic home industry in Klaten, Indonesia [11].

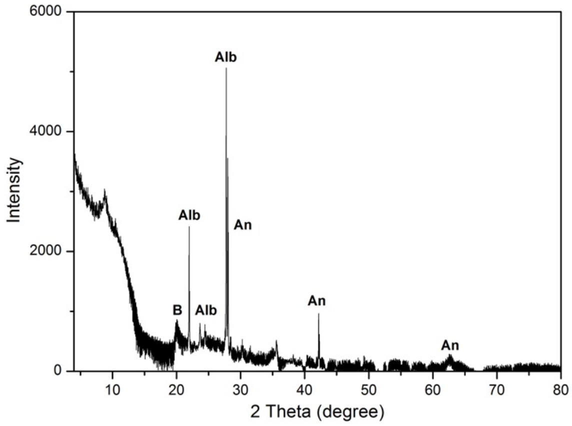


Figure 3. X-ray diffraction analysis of clay from Buleleng: Alb – albite; An – anorthite; B – biotite

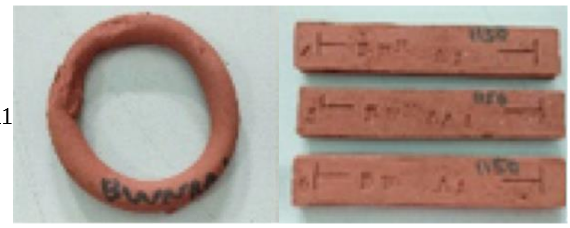
The plasticity index of the clay, measured according to the Atterberg limits, is 22.33% (Table 3), which corresponds to the plasticity category according to the Atterberg national soil plasticity test standard [22]. Moreover, bending testing of the ceramic specimen has shown that the mixture has a plasticity behavior, which is able to bend with little or no cracking, as seen in Figure 4.

Table 3. Plasticity of clay according to the Atterberg limits

Parameters	Unit	Measurement
Liquid limit	wt.%	56.07
Plasticity limit	wt.%	33.74
Plasticity index	wt.%	22.33
Description		Plasticity

(a) (b)

BWNAA1



BWNAA2

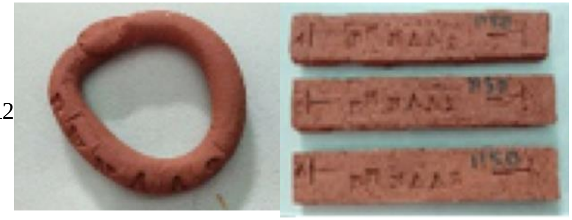


Figure 4. Bending test of clay (a); rectangular bars of earthenware specimens (b)

Both compositions exhibit plasticity behavior and the same average dry shrinkage of 6.1%, while other ceramic properties are slightly different, as shown in Table 4. The firing shrinkage of BWNAA1 and BWNAA2 are 5.4 and 5.7%, respectively. The lower shrinkage may be the result of a higher amount of quartz sand, which is consistent with previous study [23]. These shrinkage levels are still favorable for the earthenware ceramic production.

Table 4. Ceramic properties of the specimens (wt%)

Raw materials	BWNAA1	BWNAA2
Plasticity	50	50
Dry shrinkage	6.1	6.1
Firing shrinkage	5.4	5.7
Total shrinkage	11.1	11.4
Water absorption	12.2	10.8

The water absorption rate increases when the shrinkage is lower. This phenomenon also occurred in the study conducted by Osemenam et al. (2019) [24] and Subari et al. (2021) [5]. The water absorption (*WA*), however, is rather excessive for BWNAA1 and is 12.2%. The percentage of *WA* for earthenware ceramics is preferably at a maximum of about 10% [19], which is more suitable for BWNAA2. The lower WA in BWNAA2 may be due to the use of more feldspar in the mixture. This is probably because fluxing components such as feldspar can reduce the water absorption of the ceramic body [25]. After the firing temperature reaches 1150ºC, the feldspar melts and fills the pores, resulting in a denser ceramic body mass and a lower percentahe of water absorption.

On the other hand, ten cracked sample products have shown much higher water absorption data (Table 5).

Table 5. Water absorption data of the cracked ceramic samples from local products

Cracked samples	Weight, g		*WA*, %
	Dry	Saturated	
1	50.7	61.8	21.9
2	45.3	58.6	29.4
3	91.8	113.2	23.3
4	93.0	115.1	23.8
5	67.4	84.1	24.8
6	49.9	62.0	24.2
7	69.1	86.7	25.5
8	44.0	56.0	27.3
9	49.3	62.3	26.4
10	64.8	82.6	27.5
Total	62.53	78.24	25.41

On average, the water absorption rate is 25.41%, which is more than double that of the specimens in this study. Sujana et al. (2019) [17] studied the effect of firing temperature on water absorption and flexural strength, which revealed a trend where higher *WA* corresponds to lower strength. Therefore, such a high *WA* may be an indication of cracking and breaking of the earthenware products in Buleleng.

This research has revealed how the water absorption rate can influence the cracking phenomenon in traditional ceramic. However, for better understanding of cracking that occurs in this typical ceramic material, there is a need to study other factors, such as the effect of adding certain ingredients, firing temperatures, heating rate, and microstructures on ceramic specimens.

4. Conclusions

The characterization has revealed that the clay from Buleleng is mainly composed of SiO_2, AL_2O_3 and Fe_2O_3 according to XRF analysis. The high amount of Fe_2O_3 contributes to the reddish-brown color of clay bodies after firing at a high temperature. The clay mineral is marked with a hump on the XRD diffractogram, which reflects the plasticity properties. Albite and anorthite minerals have also been identified in the clay. On the basis of Atterberg limits, clay is categorized as a plastic material.

According to the results of this study, the existing problem of cracks in the ceramic production in Buleleng may be caused by high water absorption rate. It is confirmed that cracks can occur in ceramic materials with a high water-absorption rate in this case at the level of 25.41%. Developing the ceramic mixture by adding other ingredients such as kaolin, feldspar, ball clay and quartz can effectively reduce water absorption by 10.8%, which helps to prevent cracking. It can also be concluded that the clay from Buleleng is suitable for the tableware ceramic production with the addition of other additives such as kaolin, feldspar, ball clay and quartz. The decrease in the water absorption rate could be attributed to the role of feldspar as a fluxing material. Ultimately, the BWNAA2 composition, which uses more feldspar, can fulfill the requirements of ceramic properties for the type of earthenware ceramics. This improvement in ceramic properties will enhance the mechanical strength and durability of ceramic products, promoting sustainability of the local ceramic industry.

Acknowledgements

The authors would like to express their gratitude to the Head of the Creative Functional Ceramics Research Group, Denpasar, Bali; the National Research and Innovation Agency, as well as to those who helped with this research.

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Визначення характеристик глини Булеленг та поліпшення її керамічних властивостей

К.Н. Сундарі, Субарі, Б.Д. Ерланга

Мета. Дослідження можливості використання глини з Алас Ангкер в Регентстві Булеленг на Балі для виробництва керамічних матеріалів на основі доведення відповідності стандартам кераміки по типу гладких та твердих глиняних виробів, особливо для зменшення її властивості водопоглинання.

Методика. Зразки глини аналізували на її фізико-хімічний склад. Із використанням глини з кодами BWNAA1 і BWNAA2 створено дві композиції керамічного матеріалу. Зразки досліджувались з точки зору керамічних властивостей глини, включаючи пластичність, суху усадку, усадку під час випалювання та водопоглинання. Керамічні вироби з тріщинами також аналізувалися для порівняння.

Результати. Встановлено, що властивості кераміки показують схожі результати, за винятком показника водопоглинання. Визначено, що композиція з глини коду BWNAA2 має нижчий показник водопоглинання на 10.8% і відповідає вимогам до типу гладких і твердих глиняних виробів згідно з національним стандартом SNI:7275-2018. Встановлено, що показник водопоглинання становить приблизно половину від існуючої продукції, що ефективно дозволяє уникнути проблеми тріщин.

Наукова новизна. Порівняння існуючих керамічних виробів і зразків, виготовлених протягом цього дослідження, показує суттєву різницю у показнику водопоглинання та зростанні тріщин. Додавання певної кількості каоліну, польового шпату, шарової глини та кварцового піску значно знизило показник водопоглинання керамічними матеріалами.

Практична значимість. Це дослідження може бути потенційним рішенням для підвищення якості керамічних виробів в околицях Регентства Булеленг, для виробництва яких використовують глину цього типу.

Ключові слова: *глина Булеленг, звичайна кераміка, керамічний матеріал, водопоглинання*