JOURNAL OF SCIENCE AND TECHNOLOGY
ISSN: 2229-8460 e-ISSN: 2600-7924

JST

Vol. 17 No. 1 (2025) 33-40
https://publisher.uthm.edu.my/ojs/index.php/jst

Characterization of The Properties of South Lampung Clay as Lightweight Expanded Clay Aggregate

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DOI: https://doi.org/10.30880/jst.2025.17.01.004

Article Info

Received: 14 December 2024
Accepted: 30 May 2025
Available online: 30 June 2025

Keywords

Clay, lightweight expanded, bloating, kaolinite

Abstract

Bloating properties are essential to determine clay's ability to expand and form pore structures for lightweight expanded clay (LECA) applications. South Lampung clay was taken from four different places: TN, TB1, TB2, and TJ. The clay was dried at 110°C until the water content was 7%, then ground using a ball mill to 200 mesh. The clay was formed into balls with a diameter of 10 mm and then heated at 1,050°C for 15 minutes. The chemical composition was analyzed by X-ray fluorescence. X-ray diffraction was used to analyze the crystal structure formed. Topography was analyzed using FESEM. The bloating coefficient (Cb) was calculated by comparing the volume before and after heating. Based on SiO_2, TN and TB1 meet the self-bloating standard with 52.28 and 56.82% content, respectively. However, based on Al_2O_3, only TB1 meets the minimum standard with a value of 17.46%. Based on the total flux being below 10%, all clay has the potential for self-bloating. The type of clay is kaolinite with feldspar and kaolin phases. The bloated clay was found in TB1 and TJ with values of 1.08 and 1.46. Additives are needed to increase an expansion. This study can be developed to obtain the composition of local clay, which can be applied to various fields.

1. Introduction

Lightweight expanded clay aggregate (LECA) is a clay-based lightweight aggregate that expands after being developed at a temperature of 1,050 – 1,250°C [1]. LECA is a porous ceramic product with a uniform pore structure with potato or spherical shape. The small cavities in LECA filled with abundant air provide the characteristics of lightweight, thermal insulation, and sound insulation [2]. LECA is widely used in various fields, such as concrete, due to its good physical and mechanical properties [3], adsorbent material [4], ceramics matrix [5], and its application to greenhouses and green roofs [6], [7].

The mechanism of clay formation can be divided into three stages, namely: (i) gas formation in the clay, (ii) internal pressure causing the formation of pores, and (ii) the formation of small and large pores [8]. The formation of LECA is characterized by gas and pores due to internal pressure in the material body. Clay is divided into four groups based on the bloating coefficient, namely: clay with good bloating ability with Cb > 7 - 8, medium bloating ability Cb = 4-5, poor self-bloating ability with Cb = 2-2.5, and not self-bloating ability with Cb < 2 [9]. However, according to Khafaji & Co. (2016), clay with Cb > 4 is sufficient to have self-bloating properties, and the medium level is at Cb = 2.5 - 4 [10]. Chemicals SiO_2 and Al_2O_3 are also determinants in the self-bloating properties of clay.

According to Rilley's Theory, previous studies show that self-bloating clay can be predicted using the SiO_2—Al_2O_3—flux ternary diagram. This diagram facilitates the identification of whether clay expands on its own. A diagram makes it easier to identify whether clay expands by itself [11].

Table 1 shows the chemical composition of self-expanding clay based on various references. Kogel et al. (2006) added a requirement for a K_2O content of less than 2% [12].

Table 1 *Chemical composition of self-bloating clay*

Composition	Reference 1 [9]	Reference 2 [2]	Reference 3 [12]
SiO_2	50 – 60	53,3 – 70	50 – 60
Al_2O_3	15 – 20	15,05 – 27	15 – 20
Fe_2O_3	7 – 8	1 - 14,3	7 – 8
CaO	<8	0,2 - 3,93	<8
K_2O	-	-	< 2
CaO + MgO	<5	-	-
R_2O	2 – 3	-	-
Organic	0,5 – 3	-	-

Clays are divided into kaolinite, smectic (montmorillonite), illite, and chloritic [13]. Knowing the type of clay mineral is very important because it affects clay minerals' physical and mechanical properties [14]. Previous research has provided the clay composition needed to increase swelling without materials [2]. However, the study did not specifically explain the types of clay. This condition is not necessarily appropriate when local clay has various very complex chemical compositions. Using local clay can provide added value because the economic sustainability and sustainability of LECA production depend on the ability to use local materials effectively. Several studies have recommended using additives to produce LECA from clay. Materials such as sawdust can be added to clay to make ultra-light ceramics [15]. However, the discussion is limited to the effects of sawdust, and research on its impact on the chemical composition of various clay types has not been conducted. Different types of clay, with their varying chemical compositions, will yield LECA products with distinct characteristics.

Based on the description above, this study focused on characterizing LECA from the local South Lampung clay. In addition to adding substantial value, using local resources to create LECA encourages participation and a sense of connection with the research. The investigation into the suitability of South Lampung clay for LECA production involved analyzing its chemical composition using X-ray fluorescence (XRF), crystal phase using X-ray diffraction (XRD), microstructure using scanning electron microscopy with energy-dispersive X-ray spectroscopy (SEM-EDS), and bloating coefficient (C_b).

Nomenclature	
LECA	Lightweight expanded clay
C_b	Bloating coefficient
TN	Clay from Natar
TB1	Clay from Tanjung Bintang 1
TB2	Clay from Tanjung Bintang 2
TJ	Clay from Jatiagung

2. Materials And Method

Clay from the South Lampung district consisted of Natar clay (TN), Tanjung Bintang 1 clay (TB1), Tanjung Bintang 2 clay (TB2), and Jatiagung clay (TJ). The clay material was cleaned by separating the gravel and roots directly. It was washed using water and then oven-baked at 110°C until the water content was 7%. After this, the clay was ground using a planetary ball mill until it reached a particle size of 200 mesh. The resulting clay powder was mixed with 10% water using a mixer and then formed into balls in 10 mm diameter using a pan granulator. The clay balls were burned at a heating rate of 10°C/min until they reached 1,050°C in a muffle furnace and held for 15 minutes. The selection of temperature 1,050°C is based on the minimum temperature range for LECA production in general [1]. In addition, at a temperature of 1,050°C, there is expected to be an expansion due to gas generation, which results in the formation of LECA pores. The LECA product was cooled to room temperature after processing. To calculate the bloating coefficient (C_b), the volume of the material was evaluated before and after heating (Eq. 1). Analized XRD and XRF required particle size of 325 mesh of the particle by planetary ball mill. The chemical composition of the source material and the LECA product was determined using X-ray fluorescence (XRF) using

J. of Science and Technology Vol. 17 No. 1 (2025) 33-40

the PANanalytical Epsilon 3 instrument. Crystallography was tested using X-ray diffraction (XRD) with a PANanalytical ExPert 3 Powder instrument. Additionally, field emission scanning electron microscopy (FESEM) was performed with a Scientific Quattro to analyze the distribution of particles and the chemical elements present in the LECA.

$$C_b = \frac{V_2}{V_1} \tag{1}$$

Where C_b is coefficient of bloating, V_2 is volume after heating, and V_1 is volume before heating.

3. Result And Discussion

3.1. Chemical composition of clay

The dominant composition of Natar clay consists of 52.287% SiO_2, 25.010% Al_2O_3, 18.805% Fe_2O_3, 0.674% CaO, and 1.358% total flux. Tanjung Bintang 1 clay shows a SiO_2 content of 56.826%, 17.467% Al_2O_3, 20.734% Fe_2O_3, 0.530% CaO, and 1.034% total flux. Tanjung Bintang 2 clay shows a SiO_2 content of 49.2%, 24.7% Al_2O_3, 21.6% Fe_2O_3, 0.7% CaO, and 1.2% total flux. Jatiagung clay shows a SiO_2 content of 77.2%, 8.9% Al_2O_3, 8.3% Fe_2O_3, 5% CaO, and 1.3% total flux. The chemical composition of South Lampung's raw clay materials is displayed in Table 2.

Table 2 *Results of XRF characterization of clay materials*

Comp'	TN (%)	TB 1 (%)	TB 2 (%)	TJ (%)	Reference 1 [12]	Reference 2 [9]
SiO_2	52.287	56.826	49.225	77.206	50-60	50-60
Al_2O_3	25.010	17.467	24.739	8.912	15-20	15-20
Fe_2O_3	18.805	20.734	21.611	8.320	7-8	7-8
CaO	0.674	0.530	0.729	0.773	< 5	<8
TiO_2	1.376	2.136	1.991	2.630	-	-
K_2O	0.684	0.504	0.497	0.600	< 2	-
CuO	-	0.138	-	-	-	-
P_2O_5	0.792	0.803	0.724	0.872	-	-
MnO	-	0.283	0.105	0.164	-	-
ZrO_2	-	0.249	0.162	0.344	-	-
Fluks Total	1.358	1.034	1.226	1.373	< 10	

The SiO_2 content of 50 - 60 wt% clay that meets the standards are TN and TB1, with 52.28 and 56.82% values, respectively. However, based on the Al_2O_3 content, only TB1 met the standard of 17.46%. Although TJ has the most negligible Al_2O_3 content, with a value of 8.91%, this clay has the closest Fe_2O_3 content of 8.3%.

Based on the total flux in the raw clay material of South Lampung, the four clays are below 10%, so they have the potential for self-bloating. The ternary diagram shows clay's bloating properties based on the Rilley theory, shown in Figure 1. The SiO_2/Al_2O_3/flux ratio is not optimal and is outside the cell-bloating zone. The ratio imbalance causes the silicate melt to have low viscosity during combustion, so the gas cannot be trapped during mineral decomposition. As a result, the internal gas pressure is not enough to form a stable pore structure. According to this theory, clay will expand more quickly if there is a balance between SiO_2 - Al_2O_3 - total flux [11]. In theory, the four clay samples do not have sufficient viscosity to trap many gas components, making it challenging to produce a swelling local structure. The method that can be used to obtain a swelling LECA structure, based on the position of the four clay samples, is by adding Al_2O_3 and flux. However, from several previous studies, materials can be added to obtain swelling LECA. Sawdust can increase the bloating index to 321% [15]. Bloating agents can also be used such as kerosene [16].

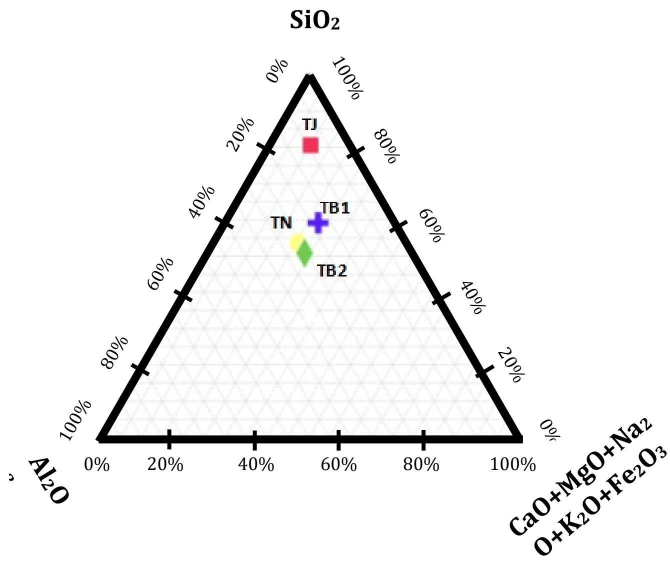


Fig. 1 *Self-bloating diagram of clay based on Riley theory*

3.2. Mineralogical Characterization

Figure 2 shows TN, TL1, TL2, and TJ clay mineralogy. The crystal phases formed in the four clay samples are quartz (SiO_2) and kaolinite ($Al_2Si_2O_5(OH)_4$), confirming that the type of clay found in South Lampung is predominantly kaolinite. Kaolinite clay ($Al_2Si_2O_5(OH)_4$) is easy to shape, has a smooth texture, does not absorb water, and does not expand when in contact with water. Although kaolinite clay has a high melting point (~1,780°C), free quartz (SiO_2) decreases the melting temperature of South Lampung clay. At a heating temperature of 1,050°C, unmelted quartz interferes with the formation of the glass phase. Consequently, the low-viscosity silicate melt cannot trap gases released during mineral decomposition. As a result, the internal gas pressure needed for the bloating process does not form. Therefore, all this clay cannot be used as a sole material for producing LECA, and additive agents are required. Clay requires additives to lower the melting point between 1,100°C and 1,200°C and gas-producing source material to support bloating ability. Therefore, clay is not suitable as the sole raw material for LECA [9].

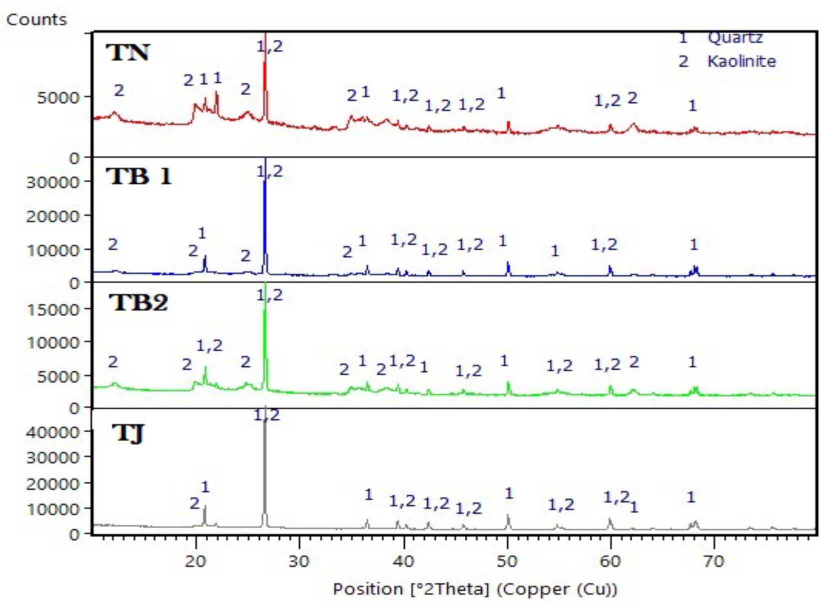
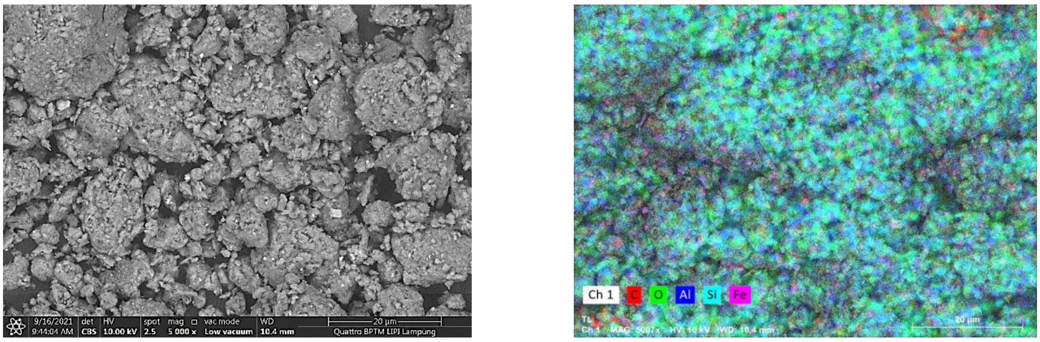


Fig. 2 *X-ray diffraction results of TJ, TB2, TB1, and TN clay*

J. of Science and Technology Vol. 17 No. 1 (2025) 33-40

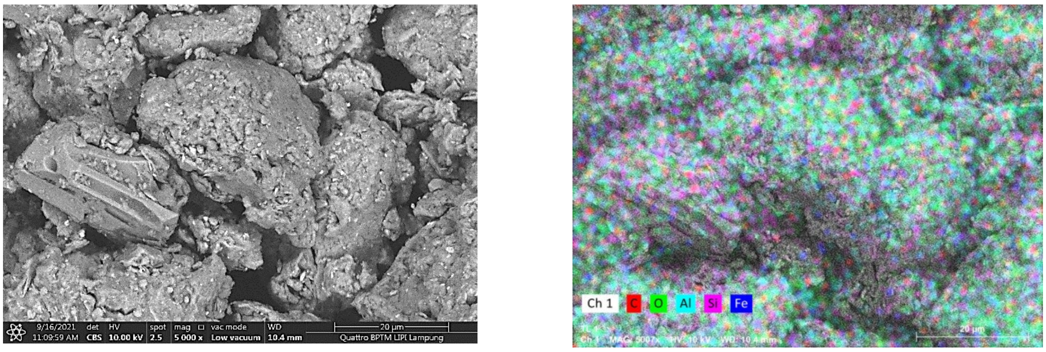
3.3. Clay Morphology

SEM analyzed the surface morphology with a magnification of 5000x, as seen in Fig. 3 - 6. The shape of the clay aggregate looks rounded to sub-rounded, where the ends of the particles form a circle and are not sharp. The sample's surface is fine to coarse-grained, indicating a quartz phase, as seen in the x-ray diffraction test. The presence of this quartz is more dominantly seen in samples of Natar clay (TN) with blue (Si) and green (O) colors, which can be seen in SEM-EDS Fig. 3. Si marked by purple is also seen in Jatiagung clay (Fig. 6). Quartz (SiO_2) in Jatiagung clay is more dominant than other chemical elements. In Tanjung Bintang 2, clay, Al, marked in blue, is more prevalent than other elements. The Tanjung Bintang 2 clay is physically whiter than other clays (Fig. 5). Meanwhile, in Tanjung Bintang 1 clay, the distribution of Si and Al is evener (Fig. 4).



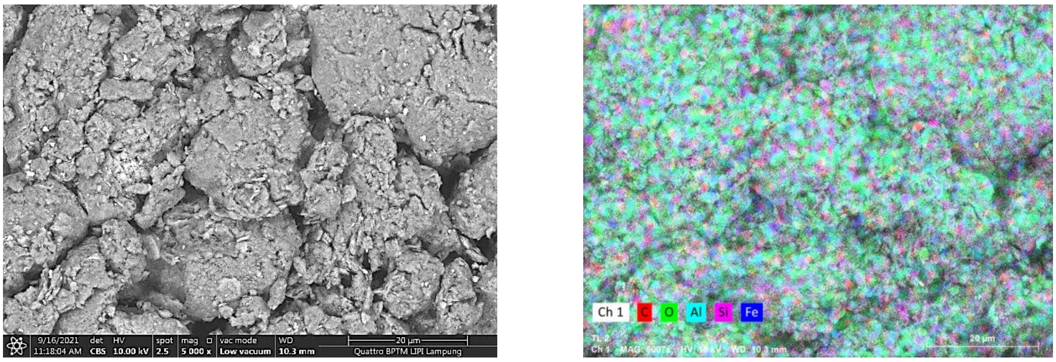
(a) **(b)**

Fig. 3 *Natar clay sample results (a) at 5000x magnification; (b) SEM EDS*



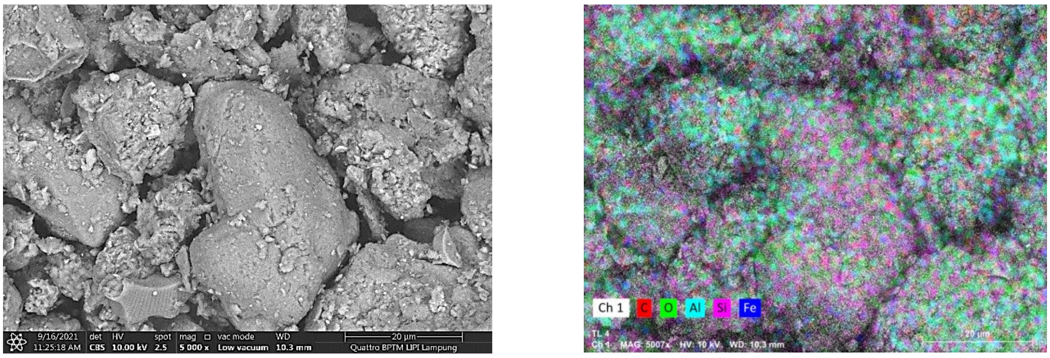
(a) **(b)**

Fig. 4 *Tanjung Bintang 1 clay sample (a) at 5000x magnification; (b) SEM EDS*



(a) **(b)**

Fig. 5 *Tanjung Bintang 2 clay sample (a) at 5000x magnification; (b) SEM EDS*



(a) (b)

Fig. 6 *Jatiagung clay sample (a) at 5000x magnification; (b) SEM EDS*

SEM results show differences in the surface structure of the four clays. Clay aggregates with abundant and even pore structures tend to have better Cb. These pores are formed by internal pressure caused by trapped gas during firing. In contrast, clays with dense or few pore structures show the inability to trap gas pressure. The presence of silicates in dominant clays increases the viscosity of the melt and inhibits the formation of stable pores.

3.4. Bloating Coefficient Analysis

Based on preview study, the coefficient of bloating was measured after heating at a temperature of 1,050°C [1]. The physical results of clay have been seen in Fig. 8.

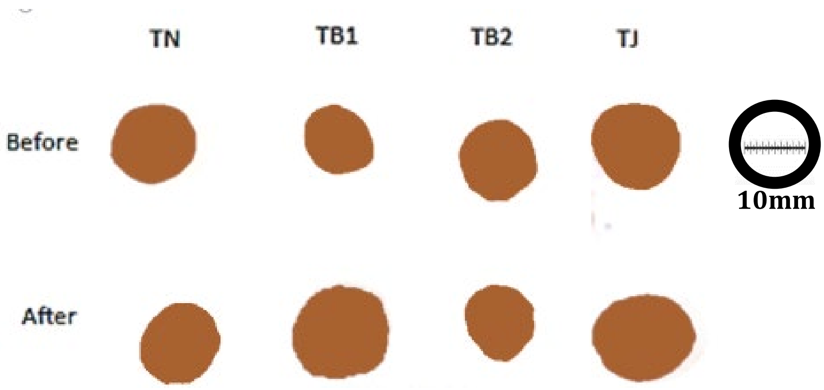


Fig. 7 *Before and after heating of South Lampung clay*

The clay bloating coefficients are shown in Table 3.

Table 3 *Bloating coefficient (C_b) of South Lampung clay*

Parameters	TN	TB1	TB2	TJ
$V_1\ (Cm)^2$	1.21	1.47	1.38	1.16
$V_2\ (Cm)^2$	0.91	1.60	1.09	1.70
C_b	0.75	1.08	0.78	1.46

Bloating clays are found in Tanjung Bintang 1 (TB1) and Jatiagung (TJ), with Cb of 1.08 and 1.46, respectively. The combustion temperature plays an essential role in bloating the clay. The dark color change on the LECA results from heating due to reduced Fe_2O_3 to FeO at high temperatures [17]. The four types of clay from Lampung Province, which have Cb values of less than 2, are classified as non-self-bloating clays [9-10]. This characteristic aligns with the findings from the SiO_2/Al_2O_3/flux diagram plot, which indicates that these clays do not expand on their own without additives. Given the low Cb value, incorporating additive materials, either organic or inorganic, is an effective solution to enhance the expansion of clay aggregates. These additives can be either organic or inorganic [18].

The four clays from South Lampung in this study are classified as clays with low Cb content. Clay from Boyolali, as studied by Wahyudi & Rosmayanti (2020), has a Cb of 2.5 to 4.5. This high Cb is obtained by adding sawdust and kerosene [1]. Clay from Iraq has a Cb of 1 to 3. The clay contains 44.28-55.57% SiO_2, 8.62 - 14.91% Al_2O_3, 3.88 - 13.86% CaO, and 0.37 - 1.46% K_2O. Compared to clay from Iraq, the four clays from South Lampung have wider variations in SiO_2 and Al_2O_3 content [10]. The addition of sawdust also affects increasing Cb in non-self-expanding clay. Non-self-expanding clay from Guangxi province, China, can expand up to 3.21 times [15]. The Water absorption of LECA is shown in Table 4. Immersion was carried out using a container filled with water at room temperature for 24 hrs.

Tabel 4 *The water absorption of LECA*

Parameters	TN	TB1	TB2	TJ
D (g)	0.91	1.6	1.28	1.7
W (g)	1.17	1.82	1.34	2.48
Water Absorption (%)	0.29	0.14	0.05	0.46

The absence of pores on the LECA surface and the low Cb value are the causes of low water absorption. High temperatures significantly affect the formation of the glass phase in the flux to close the LECA pores [1]. The water absorption of LECA is significantly influenced by its microstructure and chemical composition. By acting as a natural flux, iron (III) oxide (FeO_3) produces a glassy phase when heated. When too much of this glass phase is present, the pores on the surface of the LECA may become closed off, resulting in less water absorption. Furthermore, the creation of pores is also influenced by other chemical factors. SEM-EDX studies show that a smoother surface with fewer pores resulted in a more uniform dispersion of silicon and aluminum.

4. Conclusion

Clay from South Lampung is classified as kaolinitic clay, containing 49–77% SiO_2 and 8–25% Al_2O_3, with a total flux of less than 10%. At the same time, Jatiagung clay and Tanjung Bintang 1 clay meet the SiO_2 requirements needed for self-bloating. The presence of a significant amount of free quartz and the chemical imbalance of SiO_2, Al_2O_3, and flux outside the Rilley zone results in low silicate melt viscosity. The bloating coefficient only goes from 1.08 to 1.46 as a consequence. The uneven distribution of silicon (Si) and aluminum (Al) on the rough aggregate surface indicates that stable pores have not yet formed. The low water absorption suggests that only a limited number of open pores are present. Moreover, the predominance of the glass phase in the structure affects these pores. Overall, the low water absorption further confirms the presence of only a few open pores.

Acknowledgement

The authors acknowledge the facilities, scientific and technical support from Advanced Characterization Laboratories Lampung, National Research and Innovation Agency through E- Layanan Sains, Badan Riset dan Inovasi Nasional: All authors contributed equally, have read and agreed to the published version of the manuscript.

Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** *Author YH,* ***data collection:*** *Author AA;* ***analysis and interpretation of results:*** *Author TOR, Author BH;* ***draft manuscript preparation:*** *Author YH, Author AA. All authors reviewed the results and approved the final version of the manuscript.*

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