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Research Article

Effect of Fly Ash Variation and Heating Temperature on Physical Properties, Chemical Composition, Phase Structure, and Morphology in Making Red Brick

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Abstract
Red brick is a building material that can be used as a construction material. Red bricks are made of pure clay or mixed materials. This study aimed to determine the effect of fly ash and heating temperature variations on physical properties (compressive strength, density, porosity, and absorption), chemical composition, phase structure, and morphology in brick making. The addition of fly ash by 10%, 20%, 30%, 40%, and 50% of the composition of the material is 750 grams. The red bricks were printed with a size of 5 x 5 x 5 cm^3, heated at 700°C and 800°C for 2 hours, and soaked for 24 hours. Physical tests include compressive strength test, density test, porosity test, and absorption test, as well as red brick characterization, namely XRF, XRD, and SEM-EDS. Red brick with sample A10 at a temperature of 700°C has the highest compressive strength value of 3.68 Mpa, while red brick with sample A10 at a temperature of 800 °C has the highest compressive strength value of 4.17 Mpa. Characterization shows that the phases formed in red brick are quartz (SiO_2), hematite (Fe_2O_3), and anorthite (Al_2O_3).

Keywords: Clay; fly ash; physical test; characterization

1. Introduction

Along with the increasing population in Indonesia, the need for facilities and infrastructure in the development field also continues to increase. The rapid development growth increased the use of building materials, especially red brick. Because of its strong structure and affordable price, red brick remains the choice as the primary material in manufacturing walls (Ardi, 2016). The community's increasing need for building materials such as bricks must be accompanied by a sufficient supply of bricks and quality. That's why it's needed an alternative that can improve quality brick. One of the things to do to improve the quality of red brick is to add ingredients mixed into the composition of manufactured red brick (Dinata et al., 2013).

Red brick is usually used as a buffer or barrier wall in construction (Abdurrohmansyah et al., 2015). The main ingredient in making red bricks is clay. The clay content consists of silicon oxid

(SiO_2), aluminum oxide (Al_2O_3), iron oxide (Fe_2O_3), lime (CaO), and magnesium (MgO) (Suseno et al., 2012). Clay has some plastic properties when wet, and when it is dry, it becomes problematic. Meanwhile, if the clay is burned, it will become strong and solid (Huda and Hastuti, 2012).

Coal can be used as raw material for steam power plants. With the increasing number of steam power plants industries, the waste produced is also more abundant so that it can pollute the environment. When burning coal at the power plant, there is solid waste such as fly ash and bottom ash. To overcome it, it is necessary to find a treatment for it by being used as a chemical stabilizing agent for soil piles, the stabilization material used is fly ash. The chemical constituents of fly ash include silica, alumina, ferrous oxide and calcium oxide. The content has a self-cementing property (the ability to harden and increase strength when reacting with a liquid in the form of water) (Triadi et al., 2020).

Researchers have extensively investigated the use of fly ash in the construction industry to improve the properties of a material (Sobolev et al., 2013). The use of fly ash has been carried out in several engineering fields. One is that fly ash has been used in civil engineering, such as a mixing material for red brick or concrete. The use of fly ash in red brick construction can improve quality and durability. This is due to the silicate fly ash's pozzolanic binding of free lime, thus forming a denser and more impermeable surface (Brown et al., 2015). Fly ash can bind like cement. Still, in the presence of air and acceptable size, the silica oxide contained in coal will react chemically with calcium hydroxide formed from the hydration process. It will produce substances that can bind (Djiwantoro, 2001).

The fly ash waste used in this study was obtained from the coal combustion of steam power plants Tarahan, South Lampung, Lampung. The addition of fly ash by 10%, 20%, 30%, 40%, and 50% of each variation. The red brick was heated at a temperature of 700°C and 800°C for 2 hours, and the red bricks were soaked for 24 hours. Furthermore, the red bricks were subjected to physical tests, including the density test (measurement of mass per unit volume of objects), porosity test (percentage of space of concrete to the volume of red bricks), and absorption test (percentage of water absorbed by red bricks), as well as mechanical tests such as the compressive strength test (the ability of red bricks to withstand pressure). The characteristics of red bricks were X-Ray Fluorescence (XRF) to determine the chemical composition, X-Ray Diffraction (XRD) to determine the structure of the formed phase, and Scanning Electron Microscopy – Energy Dispersive Spectroscopy (SEM-EDS) to determine the morphology of the brick surface red.

2. Methods

This research was conducted from February 14 to April 14, 2022, in the Non-Metal Laboratory Mining Technology Research Center, National Innovation Research Agency (BRIN), Jl. Ir. Sutami, Serdang, Tj. Bintang, South Lampung, Lampung,BRIN, South Lampung. The ingredients for making red bricks are fly ash from steam power plants Tarahan, South Lampung, clay from Rejosari Village, Natar, South Lampung, and water.

The first step is to prepare the materials that will be used in the manufacture of red brick products. The ingredients are weighed according to the composition in Table 1. The next step is to mix the ingredients and add water until all the ingredients become homogeneous. Then it was printed using a $5 \times 5 \times 5$ cm^3 cube mold and allowed to stand for 24 hours. After being released from the mold, the red bricks were heated in a furnace at temperatures of 700°C and 800°C, which were held for 2 hours. After that, the density, porosity, absorption, and compressive strength tests were carried out and characterized by XRF, XRD, and SEM-EDS methods.

Table 1. Variation of material composition

Sample Code	**Composition (Clay % : Fly Ash %)**	**Material Composition**		
		Clay (g)	**Fly Ash (g)**	**Water (ml)**
A10	90:10	675	75	200
A20	80:20	600	150	220
A30	70:30	525	225	240
A40	60:40	450	300	260
A50	50:50	375	375	280

3. Result and Discussion

Based on the results of red brick research using fly ash additives to clay, the following results were obtained.

3.1. Results of X-Ray Fluorescence (XRF) Characterization of Clay and Fly Ash

The results of XRF characterization on clay are shown in Table 2.

Table 2. Results of XRF characterization of clay

No	Oxide Compounds	Amount (%)	
		Fly Ash	Clay
1.	SiO_2	53.57	62.41
2.	Al_2O_3	29.24	14.50
3.	Fe_2O_3	12.50	8.24
4.	K_2O	2.76	1.14
5.	CaO	1.08	4.43
6.	TiO_2	0.81	0.47
7.	LOI	-	2.05
8.	Na_2O	-	1.67
9.	MgO	-	5.08

In Table 2, the results of the characterization of this clay are from previous research by Suseno et al. (2012) that the clay content has the most dominant silica compound because silica compounds have the property of increasing strength in the manufacture of red bricks. The red brick strengthens because of the filling of the empty space left by evaporation from the heating process of the red brick with fused silica in such a way that the red brick becomes denser.

The results of fly ash characterization in Table 2. are by ASTM C618-08a that the fly ash is fly ash with class F standards. This is because the total SiO_2, Al_2O_3 and Fe_2O_3 is more than 70%, and the CaO content is less than 10% based on SNI S-15-1990-F, class F fly ash comes from bituminous coal (Kim et al., 2020). Therefore, fly ash from Trahan, South Lampung, can be used as an additive in manufacturing red bricks because it meets SNI and ASTM standards.

3.2. Red Brick Porosity Test Results

The results of the red brick porosity test are shown in Figure 2.

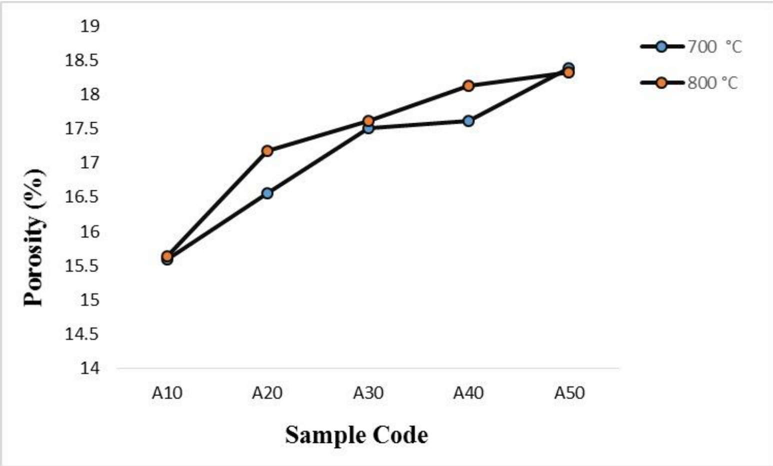

Figure 1. The relationship between composition variation and heating temperature on the porosity of red bricks

Figure 1. shows that the porosity value of the red brick heated at a temperature of 700°C with the sample code A10 has the lowest porosity value of 15.95%. Figure 1. also shows that the porosity value of the red brick has increased, so the sample code A50 is the value. The highest porosity is 18.38%. While the porosity value of the red brick heated at a temperature of 800°C with sample code A10 has the lowest porosity value of 15.64%. In addition, Figure 1. also shows that the porosity value of the red brick has increased, so the sample code A50 is The highest porosity is 18.32%. In the data above, the porosity value of red bricks has increased because the composition of fly ash is more than 10%, a decrease in compressive strength, meaning that it causes the occurrence of pore cavities in red bricks to increase. This proves that the porosity value is inversely proportional to the compressive strength and density (Zhang, 2011).

3.3 Red Brick Density Test Results

The results of the red brick density test can be seen in Figure 2.

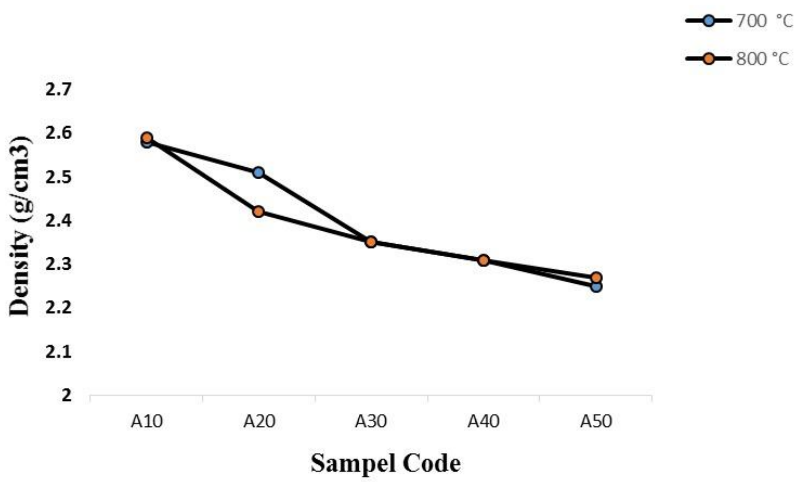

Figure 2. The relationship between composition variation and heating temperature on the density of red brick

Figure 2. shows that the density value of red brick heated at a temperature of 700°C with sample code A10 has the highest density value of 2.58 g/cm^3. Figure 2. also shows that the density value of the red brick has decreased, so sample code A50 is the lowest density value of 2.25 g/cm^3. While the density value of red brick heated at a temperature of 800°C with sample code A10 has the highest density value of 2.59 g/cm^3. In addition, Figure 2. also shows that the density value of the red brick has decreased, so sample code A50 has the lowest density value of 2.27 g/cm^3.

Figure 2. shows that the density value is directly proportional to the compressive strength value. If the density decreases, the compressive strength value also decreases. This is because the density of the red brick sample significantly affects the compressive strength value. The denser the red brick material, the higher the compressive strength value (Adi, 2009). Variations in composition also affect the density because if you use a composition with a high hardness level and a size that can enter the pores, it will affect the density value of red bricks (Wibowo, 2007).

Based on the density data, it is shown that the red brick tested complies with SNI-03-4164-1996 because it has a density with a value between 1.60 gr/cm^3– 2.50 g/cm^3.

3.4 Red Brick Absorption Test Results

The results of the red brick absorption test are shown in Figure 3.

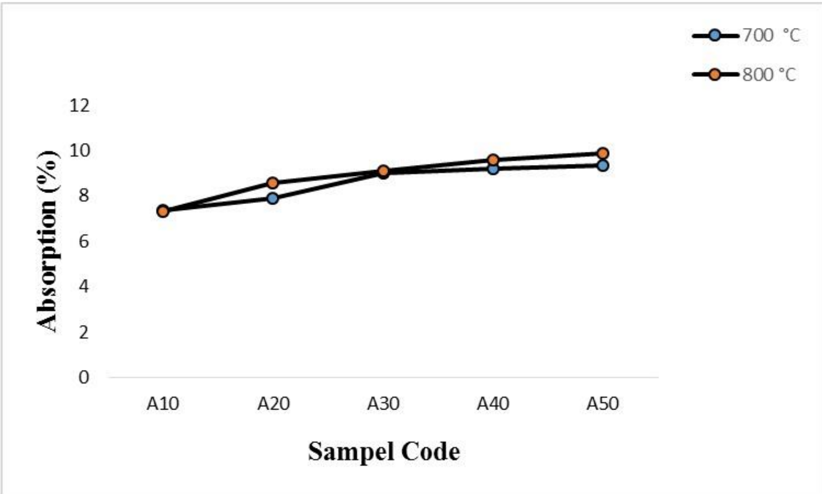

Figure 3. The relationship between composition variation and heating temperature on the absorption of red brick.

Figure 3. shows that the absorption value of red bricks heated at a temperature of 700°C with sample code A10 has the lowest density value of 7.34%. Figure 3 also shows that the absorption value of red bricks has increased, so the sample code A50 has the highest density value of 9.33%. While the absorption value of red bricks heated at a temperature of 800°C with sample code A10 has the lowest absorption value of 7.14%. In addition, Figure 3 also shows that the absorption value of the red bricks has increased, so the sample code A50 is the value. The highest density is 9.87%.

This absorption test is intended to determine how much the water absorption level is influenced by the pores or air cavities contained in the red brick material after the heating period. The larger the pore space contained in the red brick material, the greater the water absorption level, so the resistance of the red brick will decrease. This is due to the lack of density level or density of the red brick material. The decrease in absorption value is due to the high value of compressive strength and dense red brick structure, so the water absorption level is getting smaller. In addition, factors such as the type of material used, such as additives and temperature can affect the amount of water absorbed. Water absorption can also affect the strength of red bricks (Gingos and Sutan, 2011).

3.5 Compressive Strength Test Results Red bricks

The results of the calculation of the compressive strength of the red brick are shown in Figure 4.

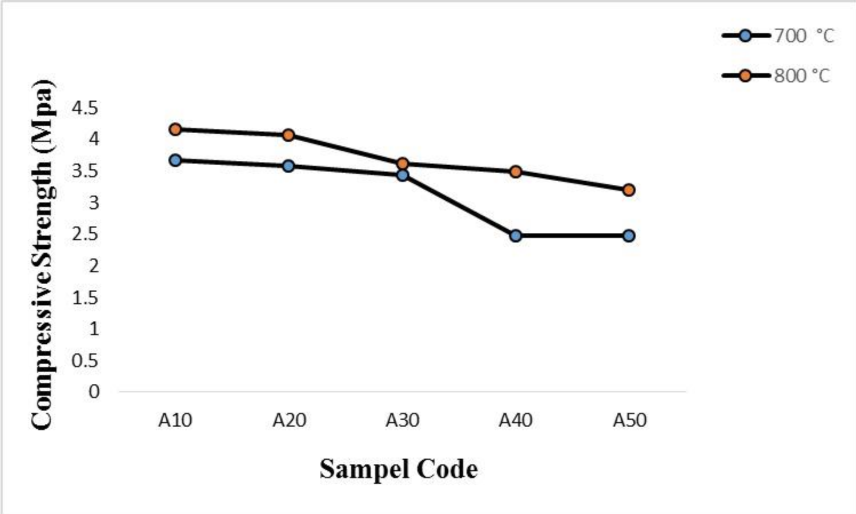

Figure 4. The relationship between variations in composition and heating temperature on the compressive strength of red bricks

Figure 4. shows that variations in composition and heating temperature can affect the compressive strength of red bricks. At a temperature of 700 °C, which has the best compressive strength, the sample code A10 is 3.68 MPa, and the sample code A50 is the lowest compressive strength value, 2.47 MPa. At a temperature of 800 °C, which has the best compressive strength, the sample code A10 is 4.17 MPa, and the sample code A50 is the lowest compressive strength value, 3.2 MPa.

Based on the compressive strength data obtained, it can be seen in Figure 4. that the use of fly ash as an additive material contributes to developing the compressive strength of red bricks. However, the use of fly ash percentage of more than 10% indicates a decreasing compressive strength value. These results are supported by research conducted by Yahya et al. (2018), that the percentage of fly ash composition of more than 10% can slow down the hardening process of red bricks. The fly ash content of more than 10% causes the mixture to become more sticky and takes longer to harden. In addition, if used excessively, the content of fly ash in the form of SiO_2 compounds will bind to free CaO and form $Ca(OH)_2$. $Ca(OH)_2$ causes the density of the red brick to decrease so that air cavities are formed in the red brick.

Based on the results of the compressive strength data, it is shown that the tested red brick meets the Indonesian Industrial Standard (SII) because it has a compressive strength with a value above 2.5 MPa and meets the class 50 standard.

3.6 X-Ray Fluorescence (XRF) Characterization Results on Red Brick

Based on the results of the compressive strength test, characterization of samples A10 and A50 was carried out. This is because sample A10 has the best compressive strength value and A50 has the lowest compressive strength value. The results of XRF characterization were carried out on red bricks with sample codes A10 and A50 at a temperature of 700 °C. XRF results on red bricks can be seen in Table 3.

Table 3. XRF characterization results on red brick

No	Senyawa Oksida	Jumlah (%)	
		A10	A50
1.	SiO_2	59.296	55.717
2.	Al_2O_3	19.501	18.759
3.	Fe_2O_3	11.177	12.092
4.	CaO	3.947	7.121
5.	K_2O	2.512	1.961
6.	P_2O_5	0.831	0.856
7.	MgO	0.268	0.428
8.	ZrO_2	0.158	0.138
9.	MnO	0.143	0.135
10.	TiO_2	1.608	1.549
11.	SO_3	0.248	0.841

Table 3. shows that the chemical composition of the two samples was dominated by the oxide compound SiO2, which was 59.296% at 10% fly ash composition and 55.717% at 50% fly ash composition. Clay and fly ash are materials that contain high SiO2 and Al2O3 compounds. Thus, when soil and fly ash are substituted as the primary material in red bricks, it can increase the levels of SiO2 and Al2O3 compounds. The more levels of SiO2 compounds in the red brick, the more Si-O-Si bonds form and create a more substantial red brick (Bakri et al., 2011).

3.7. X-Ray Fluorescence (XRF) Characterization Results on Red Brick

The results of the red brick diffractogram with sample codes A10 and A50 are shown in Figure 5.

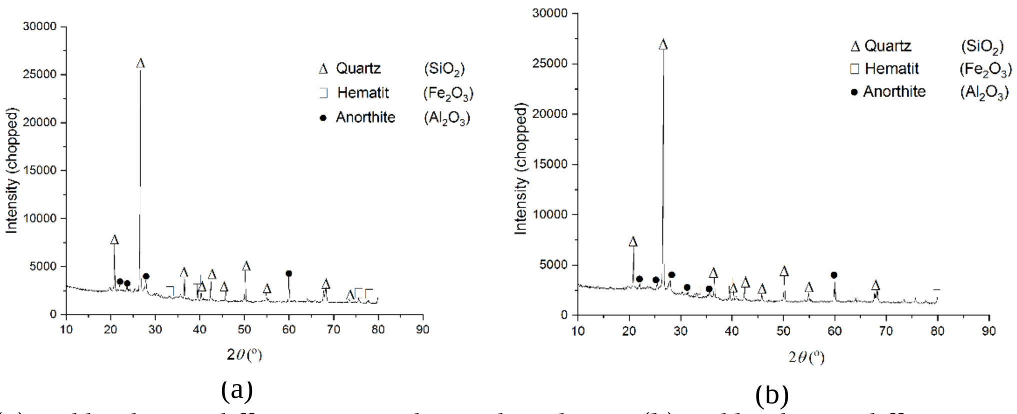

Figure 5. (a) Red brick XRD diffractogram with sample code A10; **(b)** Red brick XRD diffractogram with sample code A50

Based on Figure 5. shows that the results of XRD characterization of red bricks with sample codes A10 and A50 have conformity with the results of XRF characterization which states that SiO2, Al2O3 and Fe2O3 are the three compounds that have the highest levels contained in red bricks with sample codes A10 and A50. with the predominant SiO2 content. Therefore, the highest diffraction peaks are shown in the quartz, hematite and anorthite phases. In addition, this is also reinforced by the research of Ying Yang (2020) and A. Metha et al. (2017), where the results of XRD characterization using fly ash will be dominated by the quartz phase (SiO2).

3.8 Characterization Results of Scanning Electron Microscopy – Energy Dispersive Spectoscopy (SEM-EDS on red bricks)

The results of SEM characterization morphology on red bricks with sample codes A10 and A50 are shown in Figure 6.

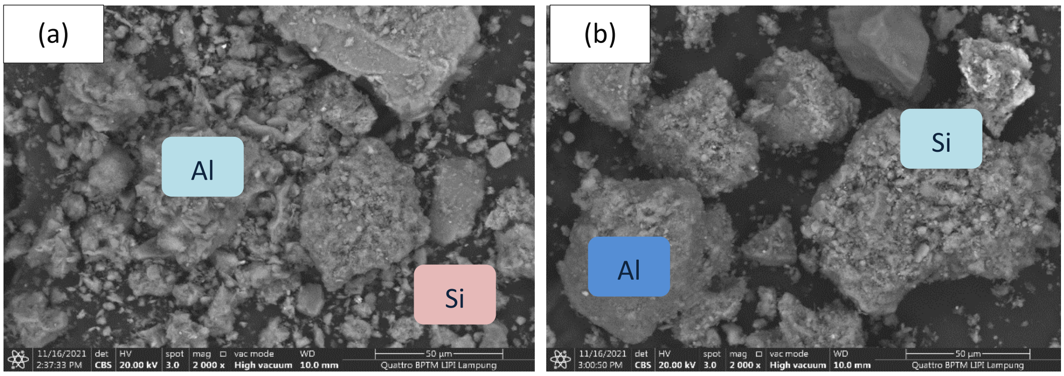

Figure 6. **(a)** The results of the morphology of the red brick SEM with the sample code A10. **(b)** Results of red brick morphology with sample code A50

The morphological results of SEM-EDS characterization on red bricks with sample codes A10 and A50 are shown in Figure 7.

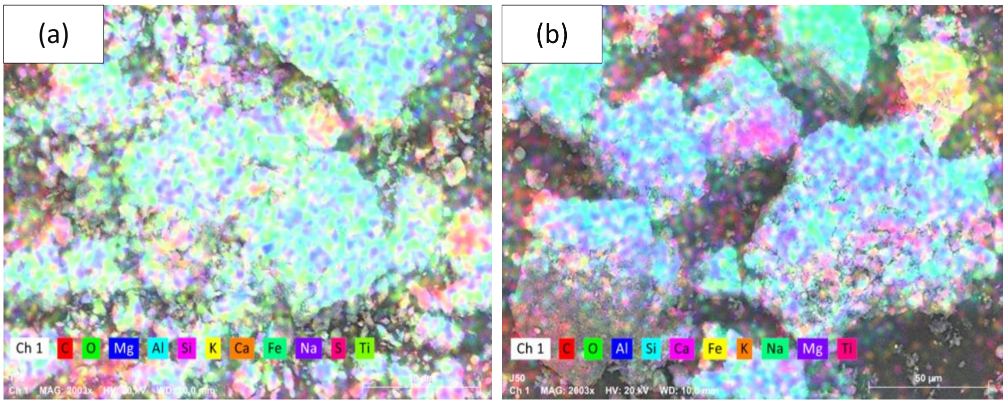

Figure 7. **(a)** Morphological results of red brick SEM-EDS with sample code A10. **(b)** Morphological results of red brick SEM-EDS with sample code A50

The results of SEM and SEM-EDS characterization of red bricks in sample A10 show that the light blue color containing the element Al and the pink color containing the Si element has an even distribution of color. The red bricks in the A50 sample indicate that the light blue color containing the Si element and the dark blue color containing the Al element has an even distribution of color. So Si and Al are the dominant elements found in red bricks. Thus, the results of the characterization using SEM-EDS are by the XRF that Si and Al are the dominant elements in samples A10 and A50. In addition, the mapping of chemical elements in the sample using SEM-EDS characterization resulted in the EDS spectrum, as shown in Figure 8.

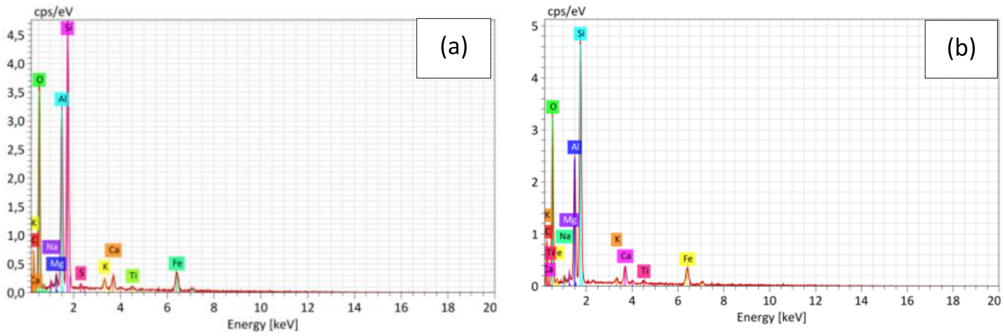

Figure 8. **(a)** Red brick EDS spectrum with sample code A10. **(b)** Red brick EDS spectrum with sample code A50

Figure 8. illustrates the EDS pattern associated with the red brick SEM-EDS analysis with sample codes A10 and A50. Figure 8. shows that Si and Al are the dominant elements. Therefore, Si and Al have the highest peaks compared to other elements. This is also reinforced by the composition of each element in Table 4.

Table 4. Composition of red brick elements with sample code A10 and A50.

No	Element	Amount (%)	
		A10	A50
1.	C	24.65	21.80
2.	O	46.50	48.39
3.	Na	0.50	0.43
4.	Mg	0.46	0.62
5.	Al	8.08	9.90
6.	Si	13.76	12.98
7.	K	0.41	0.79
8.	Ca	1.72	1.26
9.	Ti	0.33	0.35
10.	Fe	3.59	3.25
11.	S	-	0.23

In Table 4. it can be seen that the composition of each element contained in Si and Al has enormous compositional masses of 15.89% and 12.11%. In addition, the results of the characterization using SEM-EDS are by the characterization using XRF that Si and Al are the dominant elements in samples A10 and A50.

4. Conclusions

Based on the results of the research that has been carried out, it is found that the red brick with sample A10 at a temperature of 700 °C has the highest compressive strength value of 3.68 MPa and the highest density of 2.58 g/cm^3, and has the lowest porosity value of 15, 95% and the lowest abrasion was 7.34%. At the same time, the red brick with sample A10 at a temperature of 800 °C has the highest compressive strength value of 4.17 MPa, the highest density of 2.59 g/cm^3 and the lowest porosity value of 15.64% and the lowest absorption of 7.14 %. Based on the XRF characterization results, red brick's dominant chemical composition is SiO2, Al2O3, and Fe2O3. Based on the results of XRD characterization, the phases formed in red brick are Quartz (SiO2), Hematite (Fe2O3), Anorthite

(Al_2O_3), and Quartz is the highest phase formed. The results of the SEM-EDS characterization of the red bricks in sample A10 show that the light blue containing the Al element and the pink containing the Si element has an even distribution of color. The red bricks in the A50 sample indicate that the light blue containing the Si element and the dark blue containing the Al element has an even distribution of color. So Si and Al are the dominant elements found in red bricks.

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