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Preparation and properties of fired clay bricks with added wood ash

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Abstract

This study was designed to determine the effects of wood ash on the physical and mechanical properties of fired clay bricks. The clay bricks were fabricated with the addition of 0, 4, 8, 12, and 16% by weight of wood ash. Strength development of brick was cased by fired at 900, 1000, and 1100°C for 40 min. The experimental results demonstrated that the physical property and strength of the fired clay bricks depend on the wood ash content and firing temperature. Higher wood ash content affected an increase in porosity and water absorption, while the bulk density of the clay bricks was reduced. The compressive strength of the clay bricks increased with an increase in the firing temperature or a decrease in the wood ash amount. The minimum compressive strength of fired clay bricks, in accordance with the ASTM strength requirements, is 17.2 MPa and was satisfied by bricks containing 4% added wood ash fired at 1000°C and 1100°C, which attained a compressive strength of 17.9 and 19.4 MPa, respectively. The study confirmed that wood ash is a material that can be used to add extra porosity during the production of raw clay bricks.

1. Introduction

Fired clay brick is a popular building material and has been used for a long time. This brick has several advantages, including good thermal insulating property and low price. The disadvantages include heavy weight and small size. These drawbacks negatively affect its transportation and also slow down the construction speed. Recently, a number of attempts have been tried to improve these drawbacks [1]. The development of fired clay bricks to be light weight and good insulating properties that utilise agricultural and industrial waste materials has been considered. However, there are other clay brick properties that have also been claimed to be important [2].

The properties of fired clay bricks depend on the composition of raw materials, firing temperature, and production method [3]. The use of waste materials as an additive in the clay brick production allows the improvement of various properties of fired clay bricks and solves some environmental problems [4]. Agricultural waste is a common additive in clay bricks (e.g., coconut husk, grass, tea, cotton stalk, tobacco, rice husk, sugarcane bagasse) [5]. The incorporation of an additive into clay bricks leads to the generation of pores and results in reduced thermal conductivity [6,7]. The pores directly affect the fired clay bricks density and also influence various other properties of fired clay bricks. The benefits of high clay bricks porosity are the lightweight and better thermal and sound insulation [8,9].

The wood waste from the furniture industry is normally used as a fuel source in the factory. This waste composes of both inorganic and organic residues. After burning, a large amount of wood ash is obtained. The ashes are classified according to the chemical composition as high calcium ash and high silica ash. The high calcium group is produced from hardwood, while the high silica group is generated from rice straw, grass and rice husk. The mixed wood ash-clay composite was studied for use in the pavement. The use of wood ash as a fuel source is not only an important point to the industry, it also helps with environmental conservation [11].

A number of researchers have previously examined the use of wood ash in cements, ceramics materials, mortar, and concrete mixtures [12-16]. Admixtures of wood ash and sawdust were researched in the laterite-clay bricks, which was tested in accordance with ASTM C67. Wet and dry compressive strength of the bricks made from the control mix were about 18.4 and 15.2 MPa, respectively. Water absorption of the bricks made from the control mix was 13-15%. It was reported that wood ash addition presented lightweight and high porous products [17]. However, there is still a need to study the effects of wood ash on porosity, density, and strength characteristics of fired clay bricks.

This study aimed to utilize the wood ash from the power generating industry in fired clay brick composition. The effect of wood ash addition in fired clay brick on the physical and mechanical

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properties of fired clay brick was tested. The experimental result has also been extended to determine the use of its use in the insulation wall of fired clay brick.

2. Experimental

The clay used in this study was obtained from one of the local brick plants in Muang District, Nong Khai Province, Thailand. The mineralogical compositions of the clay and wood ash were analysed by X-ray powder diffraction (XRD Panalytical X' Pert PRO MPD, Netherlands). The chemical compositions of the clay and wood ash were investigated by X-ray fluorescence (XRF) elemental analysis spectrometry (Horiba MESA-500W). The particle size distribution of the raw clay was measured by laser diffraction using a Mastersizer 2000+Hydro 2000 MU (Malvern Instrument Ltd).

In order to study the effects of wood ash on the physical and mechanical properties of clay bricks, various mixture percentages of the wood ash were used (i.e., 0, 4, 8, 12, and 16 wt%). The raw clay and wood ash were mixed using a ball mill to ensure a homogenous mixture. Then, 15-30% of water was added to the mixture to obtain a desirable plastic condition. Soft-mud rectangular clay bricks (14 × 6.5 × 4.0 cm) were formed using brick hand moulding. The brick samples were air-dried at a temperature range is 30-35°C for 24 h and over dried at 110±5°C for another 24 h. The brick samples were fired at three different temperatures (i.e., 900, 1000, and 1100°C) with a heating rate of $3°C\cdot min^{-1}$ and soaking time of 40 min. Shrinkage was measured following the ASTM C326-09 standard [18]. Archimedes' method based on ASTM C373-14a [19] was used to determine the density, porosity, and water absorption. The compressive strength of the clay brick samples was measured in accordance with ASTM C773-88 [20]. The experimental results from all the tests were the mean values of 10 samples.

3. Results and discussion

The chemical compositions of the raw clay and wood ash are presented in Table 1. The major components of the raw clay were silica (SiO_2, 60.95 wt%), alumina (Al_2O_3, 16.02 wt%) and iron (III) oxide (Fe_2O_3, 10.43 wt%). The minor components were potassium oxide (K_2O, 1.67 wt%), titanium dioxide (TiO_2, 1.1 wt%), and manganese oxide (MnO, 1.07 wt%). The presence of the negligible amounts of colour oxides (i.e., Fe_2O_3) in the raw clay caused the colour change after firing. The main components observed in the wood ash were silica (SiO_2, 49.0 wt%) and calcium oxide (CaO, 17.30 wt%). The secondary components present were alumina (Al_2O_3, 3.43 wt%), iron (III) oxide (Fe_2O_3, 3.29 wt%), manganese oxide (MgO, 2.66 wt%), potassium oxide (K_2O, 1.98 wt%), titanium dioxide (TiO_2, 1.18 wt%), sodium oxide (Na_2O, 1.02 wt%), and phosphorus pentoxide (P_2O_5, 0.47 wt%). In addition, the loss on ignition (LOI) method was applied to the raw clay and wood ash after firing at 1000°C that was constituted 8.10 wt% and 19.46 wt%, respectively.

Figure 1 illustrates the X-ray diffraction patterns of the raw clay and wood ash. The XRD pattern of the raw clay clearly shows the quartz peak (SiO_2), which is the main component of the raw materials. Besides, it also displays small peaks for the minor components, such as hematite and muscovite (Figure 1(a)). While, the XRD pattern of the wood ash also shows quartz and calcium carbonate ($CaCO_3$) as the main component, (as shown in Table 1) it presents smaller peaks of wollastonite ($CaSiO_3$) and quartz (Figure 1(b)).

Table 1. Chemical composition of the raw clay and wood ash.

	Compositions (wt%)										
Raw materials	SiO_2	Al_2O_3	Fe_2O_3	CaO	K_2O	Na_2O	P_2O_5	TiO_2	MnO	MgO	LOI
Clay	60.95	16.02	10.43	0.46	1.67	-	-	1.10	1.07	0.75	8.10
Wood ash	49.0	3.43	3.29	17.30	1.98	1.02	0.47	1.18	-	2.66	19.64

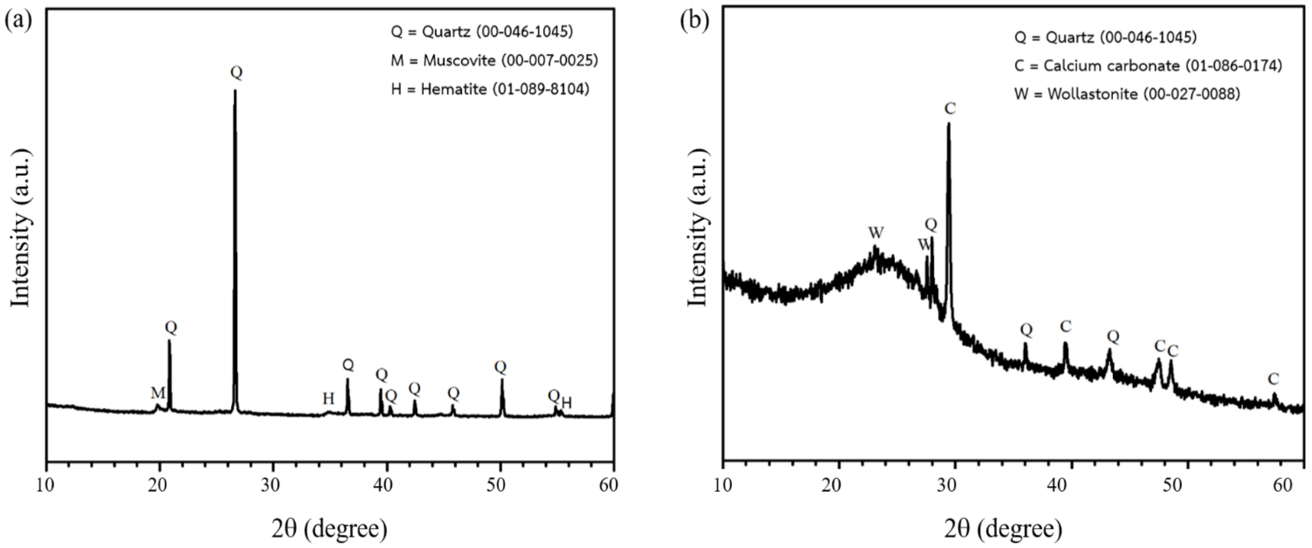

Figure 1. X-ray diffraction patterns of the (a) raw clay and (b) wood ash.

The particle size distribution analysis of the raw clay and wood ash are provided in Figure 2. The result revealed that the particle size ranges from 1-60 µm for the raw clay, and an average particle size D [4,3] (Volume mean diameter) equals to 12.05 µm (Figure 2(a)). While the particle size of wood ash is size in the ranges 0.01-1 µm, and an average particle size D [4,3] equals to 0.06 µm (Figure 2(b)). In addition, the raw clay used in the experiment was dark in colour. The particle size distribution of both raw materials is provided good compactness.

The morphology of the raw materials was investigated by the scanning electron microscope (SEM) (Figure 3). The SEM images of the raw clay powders revealed that the particles were different in morphologies, sizes, and agglomeration. The average particle size ranged from 2-40 µm (Figure 3(a)). These observations were in line with the particle size distribution as shown in Figure 2(a). The wood ash powder morphology (Figure 3(b)) contained particles of various sizes and shapes.

In general, firing shrinkage used in shaping the clay bricks occurs due to water escape from a clay body. When the clay body loses some water, the solid particles move closer together, resulting in the shrinkage of clay bricks [2,8]. Also, the firing shrinkage is associated with the degree of sintering of the sample. Normally, good quality clay bricks exhibit shrinkage below 8% after firing [21]. In this study, the clay bricks were fired at 900-1100°C with the added wood ash to increase the clay brick porosity. It was expected that the shrinkage after firing was to be higher with the increased amount of wood ash in the clay body mixture. The clay brick characteristics were also expected to change after firing at various temperatures. Because of the sintering is the bonding together of particles at high temperatures. Particles sinter by atomic movies that eliminate the high surface energy associated with the powder. On firing the cohesive necks grow of the particle contacts occur. The neck growth causes the shrinkage, porosity, density and mechanical changes. The results showed that the shrinkage of the fired clay bricks was in the range of 4.24-6.84% (Figure 4(a)). The control portion of the fired clay bricks (i.e., without any wood ash) had comparable firing shrinkage values of 4.72, 5.94, and 6.35% after firing at 900, 1000, and 1100°C, respectively.

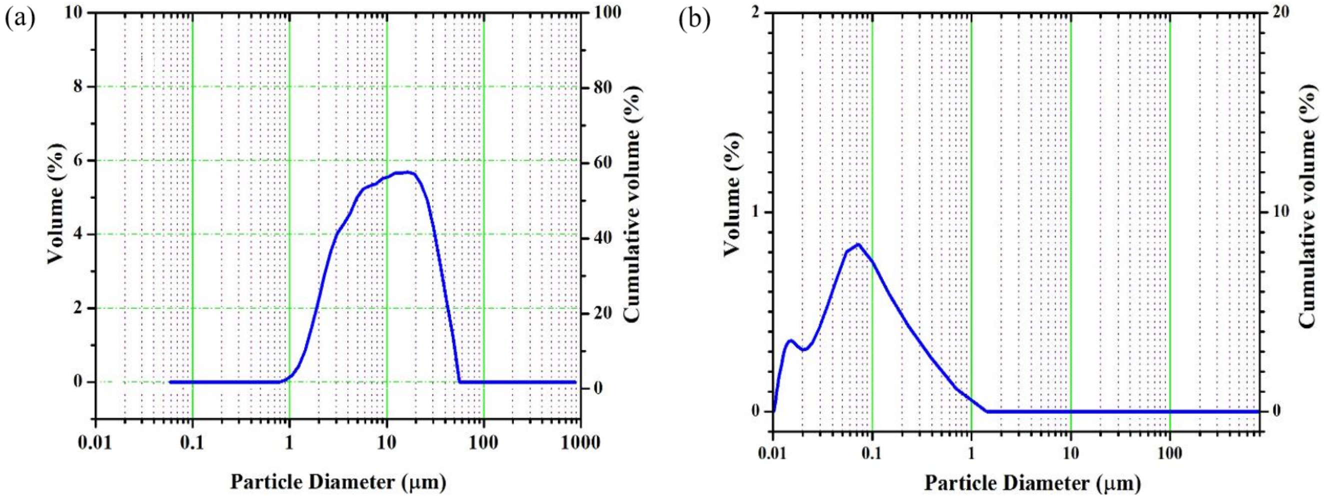

Figure 2. Particle size distribution of the (a) raw clay and (b) wood ash.

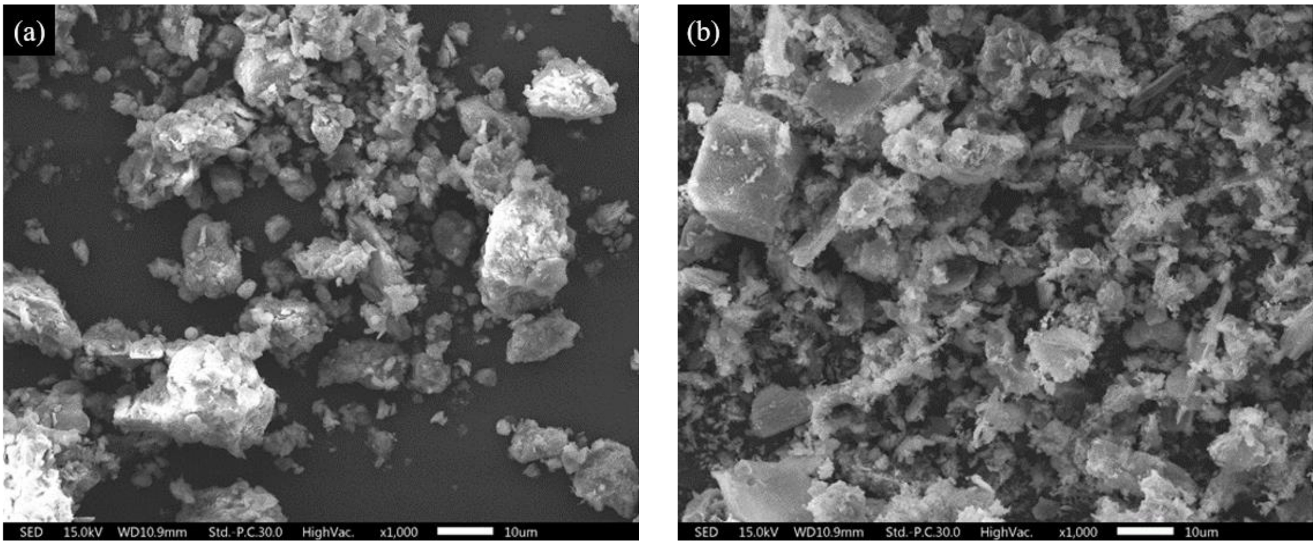

Figure 3. SEM images of the raw materials: (a) raw clay and (b) wood ash.

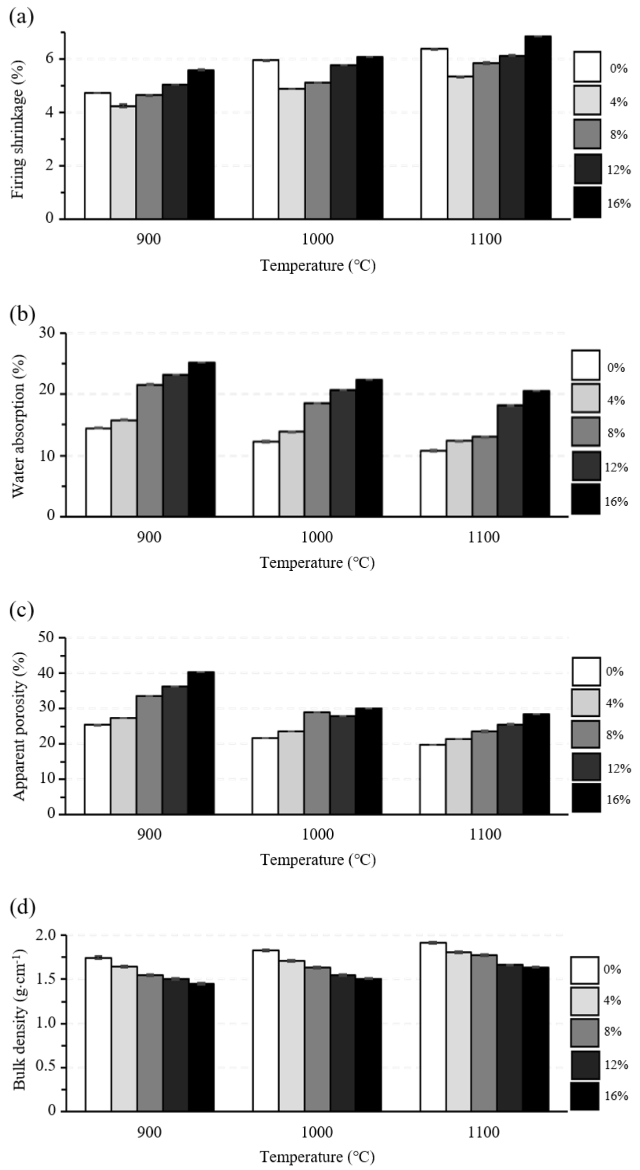

Figure 4. Physical properties of the samples fired at 900-1100°C with 0-16 wt% of wood ash: (a) firing shrinkage, (b) water absorption, (c) apparent porosity, and (d) bulk density.

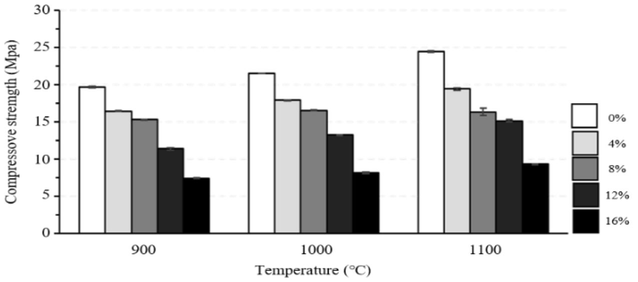

Figure 5. Compressive strength of the fired clay bricks.

Water absorption values of the fired clay bricks are presented in Figure 4(b). The durability of fired clay bricks is related to their water absorption. When water infiltrates into a clay brick, it decreases its durability [2]. During the experiment, the water absorption values slightly increased with the augmented amount of wood ash and constituted 12.3-25.2%. Furthermore, it was found that the water absorption decreased when the bricks were fired at higher temperatures. The control brick samples had comparable water absorption values of 10.8-14.5%. The water absorption values obtained in this study were consistent with ASTM C62-13a, where the Grade MW and SW bricks must have an average maximum absorption of 22.0% and 17.0%, respectively. The water absorption values typically conform to the apparent porosity values of the fired clay bricks.

Clay brick apparent porosity directly affects its water absorption. Therefore, the test results for water absorption and apparent porosity tend to coincide [2,22]. High porosity of fired clay bricks is beneficial for their thermal properties. Fired clay bricks with high porosity have low thermal conductivity, which is favourable for their thermal insulating properties [8]. This study showed that the apparent porosity of the fired clay bricks depended on the amount of the added wood ash and firing temperature. The highest porosity obtained in the fired clay bricks was 40.3% (16% of wood ash, 900°C firing temperature). The lowest porosity obtained in the clay bricks was 21.3% (4% of wood ash, 1100°C firing temperature) (Figure 4(c)). The brick porosity increased with an increased wood ash content due to the burning out of the wood ash during the firing process. However, when firing at higher temperatures, the porosity decreased because of the increase in the particles contacts occur, and, as a result, decrease porosity.

Fired clay brick density is an important parameter for the clay brick performance [8,23]. The clay brick density is essential in terms of the reduction of the overall dead load and improvement of the thermal properties. Therefore, when the fired clay brick density increased during the experiment, the clay brick strength increased, and the water absorption decreased. The test results illustrate that the bulk density values of the samples with the added wood ash varied from 1.45 to 1.81 $g\cdot cm^{-3}$ (Figure 4(d)). This figure showed that the bulk density tens to decrease with increasing of wood ash addition. However, the bulk density tens to increase with increasing of firing temperature. Evidently, the bulk density controlled the durability and water absorption characteristics of the fired clay bricks.

Compressive strength of fired clay bricks is the most important engineering-quality index for a construction material [23,24]. ASTM C62-13a specifies that the Grade MW bricks must have the minimum compressive strength of 17.2 MPa. In this study, the compressive strength of the fired clay bricks greatly depended on the amount of the added wood ash and firing temperature. The strength of the clay bricks increased with an increase in the firing temperature and a decrease in the wood ash amount. In the case of high temperatures, the compressive strength augmented due to the reduction in porosity and increase in density, because of the sintering is the bonding together of particles. For the case of wood ash addition, compressive strength was increased with a decrease of wood ash amount due to reduce in porosity in the fired clay bricks. The compressive strength for all of the samples varied from 7.42 to 19.4 MPa with the added wood ash ratios ranging from 4 to 16 wt% (Figure 5). The best results were derived with a mixture ratio of 4 wt% of wood ash for the bricks fired at 1000 and 1100°C, where the compressive strength varied between 17.9 and 19.4 MPa, respectively. These compressive strength values are adequate in comparison to 17.2 MPa, as required by the ASTM standard.

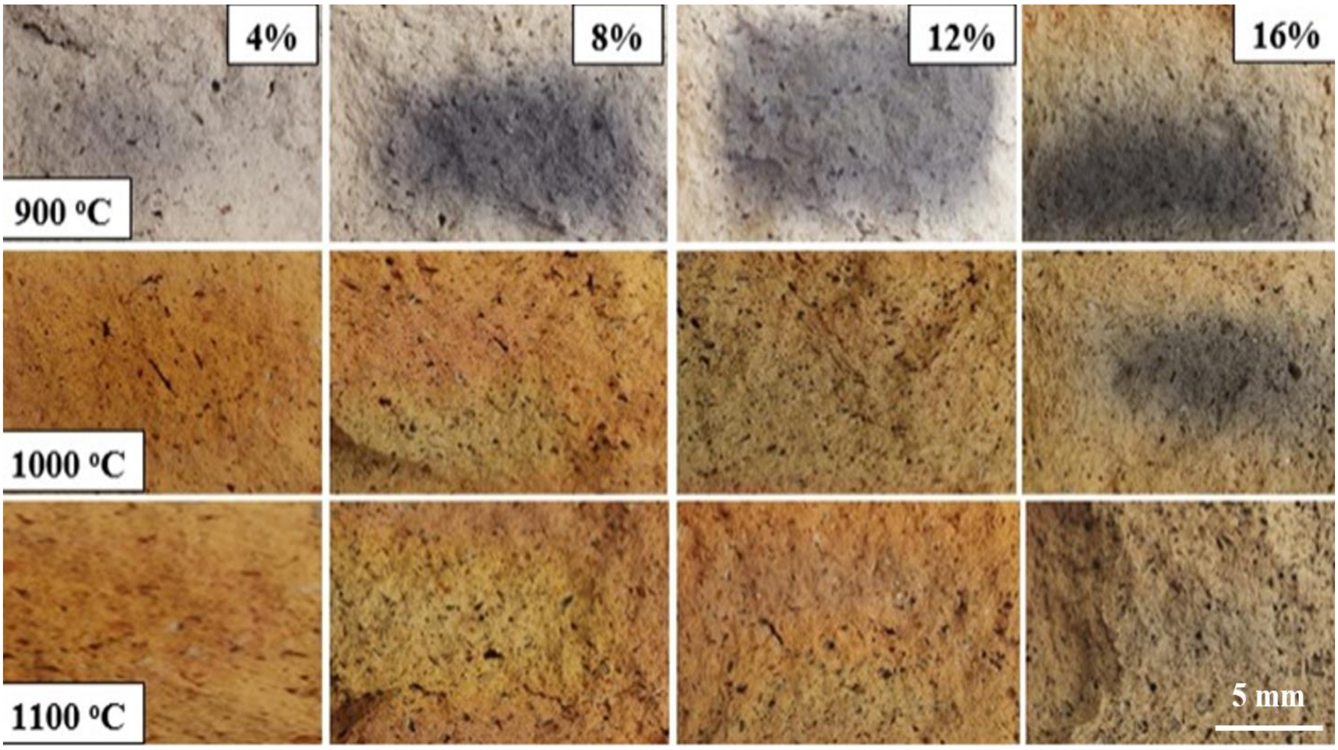

Figure 6. Cross-sectional view of the clay brick samples fired at 900-1100°C with different percentages of the wood ash.

Figure 6 illustrates a comparison of the surface textures of the clay brick samples with 4, 8, 12, and 16 wt% of the added wood ash. Those samples demonstrated different types of visible pores when fired at 900-1100°C. High porosity was observed in the fired clay bricks with a high content of the wood ash. Although an increase in porosity causes a reduction in compressive strength, it can be balanced by firing at higher temperatures [25]. It was also found that the chemical composition of raw clay and firing temperature could affect the colour of clay bricks. The effect of the added wood ash on the clay bricks can be observed in the cross-sectional view of the sample. It can be seen that the firing temperature of 900°C, the colour of bricks changed with increasing wood ash. At 16 wt% of wood ash, the colour of the bricks changed significantly and resembled the colour of good burnt bricks. At high amount of wood ash, the burning is more intense as the wood ash was also burnt and contributed to the development of bricks. At firing temperature of 1000 and 1100°C, the obtained bricks showed similar colour of good burnt bricks. The increase in wood ash content resulted in slight increase in the darker shade of the fired bricks.

4. Conclusions

The physical and mechanical properties of the fired clay bricks with the addition of the wood ash were studied. The sample compressive strength decreased with the addition of the wood ash and increased with an increase in the firing temperature. The sample compressive strength was reduced with a decrease in density owing to the formation of porosity in the fired clay bricks compared to the control clay bricks without any added wood ash. The decreased density of the fired clay bricks is useful for making bricks lighter. The compressive strength must be at an acceptable level following the established ASTM standards (C773-88) and not less than 17.2 MPa. In this study, the best compression strength was obtained for the clay bricks with a mixture ratio of 4 wt% of wood ash and fired at 1000-1100°C. The compressive strengths obtained were 17.9 and 19.4 MPa, respectively, thus in accordance with the aforementioned standard.

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