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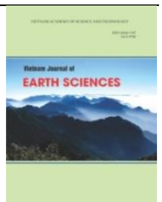

Use fly ash for the production of lightweight building materials

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ABSTRACT

Fly ash is a waste byproduct of thermal power plants or steel plants with a low density. Study on using fly ash to produce lightweight construction materials will is a new application of this material resource. Pha Lai fly ash is a byproduct from Pha Lai Thermal Power Joint Stock Company, in which the main mineral component was mullite (15-20%), quartz (14-16%), carbon (5-7%). The content of the amorphous component was about 67-73%. The chemical composition of Pha Lai mainly was SiO_2 (51.73%), Al_2O_3 (23.22%), Fe_2O_3 (4.23%). To fabricate the lightweight material from Pha Lai fly ash, the fly ash was mixed with additive materials to create binders following two ways: (1) lime + fly ash and (2) geopolymer technology. For the way of lime + fly ash, with the optimal mixture ratio was fly ash:lime: water = 10:2:1, the lightweight material samples had the bulk density of 1.32g/cm^3, the compressive strength of 3.91 MPa, satisfied the Vietnamese standard TCVN 6477-2011 for concrete bricks. Applying the geopolymer technology, with the optimal mixture ratio was fly ash: $NaOH/Na_2SiO_3$: Al powder = 100:45:0.15, $NaOH/Na_2SiO_3$ ratio = 1:2, the lightweight materials obtained the bulk density of 0.62g/cm^3, the compressive strength of 1.54 MPa, satisfied the Vietnamese standard TCVN: 9029-2017 for Lightweight concrete - Foam concrete and non-autoclaved concrete products-specification.

Keywords: Fly ash, lightweight material, geopolymer, pozzolan, lime.

1. Introduction

The use of environmentally friendly materials (green materials) is becoming an inevitable trend and the goal of the building materials manufacturing industry. The increase of demand for green materials promotes much of the research on production technology and exploration of raw materials for producing these materials, which will be chosen to substitute construction materials such as traditional bricks and concrete. One of the types of building materials that have been and will be used more widely in the future is lightweight building materials because of its advantage in high mechanical strength and durability property, thermal insulation, sound insulation, cost-saving in construction, adapting to the climate at the construction site. Furthermore, due to its lightweight, it is easy to transport.

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Especially with the strong development of technology in recent years, a lot of research and application of production technology for lightweight building materials such as lightweight bricks, lightweight panels, lightweight concrete,… to replace traditional bricks, concrete with low energy consumption has attracted more and more attention.

It can be realized that fly ash is a waste byproduct of thermal power plants or steel plants with a low density, contains a large amount of amorphous Al_2O_3 and SiO_2 in its composition. These are important factors to apply the technology of making binders such as lime + pozzolan binder or geo-polymeric binder for producing lightweight building materials based on fly ash. By applying these technologies to produce construction materials, a large amount of energy using in the production process will be reduced. Because, during making the lime + pozzolan binder, the amorphous component in fly ash will react with hydrated lime to form a binder as Portland cement which can bind materials together to create the strength and water resistance properties for materials without calcination (Kieu Q.N and Nguyen A.D., 2015; Nguyen A.D et al., 2020); and according to the reaction mechanism of geo-polymeric binder, under high alkaline conditions, the amorphous Al_2O_3 and SiO_2 contents in aluminosilicate minerals dissolve and then polymerize to yield polymeric Si-O-Al-O bonds, they can be solidified under conditions of room temperature and pressure (Davidovits, 1991; Romisuhani et al., 2015).

Moreover, in Vietnam, there are many thermal power plants and steel plants. The total amount of fly ash emitted from only 20 thermal power plants operating was about 12.5 million tons/year; by 2025, it can be estimated to reach 29 million tons/year. Therefore, a large amount of fly ash was generated. If they are not treated and utilized effectively, they will be only a waste but also a great danger to the environment because dust and toxic components in fly ash will be emitted into the environment easily.

In the world, many studies on the production of fly ash-based geopolymer building materials have been performed for a long time. These studies improve the quality of the materials and increase their application ability. In addition, some recent studies are carried out, such as the study of Subasi (2009) on the effect of using fly ash on high strength lightweight concrete produced with expanded clay aggregate; the study of Abdullah et al. (2012) on producing fly ash-based lightweight concrete using foam agent; the study of Çiçek and Çinçin (2015) on the use of fly ash and lime to produce lightweight building bricks; and a new study of Satpathy et al. (2019) on development of sustainable lightweight concrete using fly ash cenosphere and sintered fly ash aggregate.

Production of lightweight building materials in Vietnam still be limited while the demand there is increasing. Many studies on production technology of lightweight construction materials have been performed such as manufacturing lightweight concrete using keramzit gravels by the Vietnam Institute of Building Science and Technology since the 1990s; producing lightweight concrete with foam in the middle layer and steel-reinforced concrete covering its surface by Detech company, or testing production of lightweight materials from clay soil and styrofoam. Since 2009, the production technology of autoclaved concrete (lightweight concrete) has been introduced in Vietnam by ShanDong Dongyue Building

Machine Co., Ltd (China). The company provided equipment and instructed the production process of the lightweight concrete. However, the company did not master the production technology, the quality of the products is not high.

There are many studies on the application of fly ash in the construction field. Still, they mainly focus on evaluating its usability for making cement additives, concrete admixtures, mortar, for example, the study of Le V.H. (2015) or on the geo-polymeric binder in the production of non-fired building material done by Kieu Q.N. & Nguyen A.D. (2015).

The paper's goal is the effective use and the raise of the usability of available wastes, the treatment of environmental pollution, and the solution to the supply and demand problem for green building materials. In this paper, the authors present obtained researched results: mineral components and chemical composition of Pha Lai fly ash, the optimal mixture ratios of fly ash, and additives to fabricate the highest quality product.

2. Materials and methods

2.1. Materials

The main material used for producing lightweight material is fly ash which was the byproduct from Pha Lai Thermal Power Joint Stock Company. Its grain size is smaller than 1mm.

Sodium hydroxide (NaOH) powder with a purity of 98% was prepared into a 12M NaOH solution.

Sodium silicate ($NaSiO_3$) has chemical composition of SiO_2 (30.1%), Na_2O (9.4%) and H_2O (60.5%) ($SiO_2/Na_2O = 3.2$).

Pure aluminum powder has a grain size of <0.01mm.

PC30 cement of VICEM BIMSON Cement Joint Stock Company.

Hydrated lime contains >80% of CaO; the grain size is smaller than 0.08mm.

2.2. Preparation of lightweight building materials

Samples of lightweight building materials were fabricated following 2 methods: (1) Lime + pozzolan binder and (2) Geopolymeric binder.

2.2.1. Lime + pozzolan binder

Lightweight building materials were fabricated by mixing fly ash, hydrated lime, and cement at different mixture ratios shown in table 1; water was added 12% by weight to make the sample moisture; compressive force of 2.5 MPa was used to form the sample's shape. Next, the samples were molded into cylindrical specimens with the size of 5×5cm. After that, the molded samples were cured by water-saturated covers at room temperature. After 28 days, their physicomechanical properties were analyzed.

Table 1. Mixing ratios of Pha Lai fly ash with other materials (wt%)

Samples	Fly ash	Hydrated lime	Cement
VL1	100	10	0
VL2	100	15	0
VL3	100	20	0
VL4	100	15	5
VL5	100	15	10

2.2.2. Geopolymeric binder

12M NaOH solution was prepared by mixing NaOH powder with distilled water, stirring, and cooling at room temperature.

The 12M NaOH solution was mixed with Na_2SiO_3 solution to create $NaOH/Na_2SiO_3$ solution with 1:1, 2:1, 3:1. They were placed in the laboratory room, and after 24 hours, they were used to fabricate lightweight building materials.

The test lightweight building samples were fabricated by mixing Pha Lai fly ash with the $NaOH/Na_2SiO_3$ solution, Al powder, cement, and water at different ratios shown in table 2.

Next, they were molded into cylindrical specimens with the size of 5×5cm. After that, they were cured at room temperature for 24 hours, then unmolded and sintered at 50°C for 72 hours. Finally, they were allowed to mature at room temperature for 28 days. After all, they were analyzed physicomechanical properties.

Table 2. Mixing ratios of Pha Lai fly ash with other materials (wt%)

Samples	$NaOH/Na_2SiO_3$ ratio	Pha Lai fly ash	$NaOH/Na_2SiO_3$ solution	Al powder (g)	Cement	Water
GN1	1:1	100	30	0.1	0	15
GN2	1:2	100	30	0.1	0	15
GN3	1:3	100	30	0.1	0	15
GN4	1:2	100	20	0.1	0	25
GN5	1:2	100	25	0.1	0	20
GN6	1:2	100	35	0.1	0	10
GN7	1:2	100	45	0.1	0	0
GN8	1:2	100	30	0.1	5	15
GN9	1:2	100	30	0.1	10	15
GN10	1:2	100	30	0	0	15
GN11	1:2	100	30	0.05	0	15
GN12	1:2	100	30	0.15	0	15
GN13	1:2	100	30	0.2	0	15
GN14	1:2	100	45	0.15	0	0

2.2. Methods

X-ray diffraction (XRD) is used to identify and semi-quantitative analysis of a mineral component of fly ash and samples of lightweight materials. Samples were analyzed on PANalytical Empyrean XRD system at Institute of Geological Sciences - Vietnam Academy of Science and Technology (IGS-VAST), using Cukα radiation, tube working conditions of 45KV-40mA, an angular range of 5.0-70.0 °2θ, and divergence slit of 2°.

X-ray fluorescence (XRF) analysis for the chemical composition of studied samples was carried out on Bruker S4 Pioneer XRF spectrometer at IGS-VAST.

Scanning Electron Microscope (SEM) is used for microanalysis of the surface of materials. The method was carried out by FEI Quanta 650 SEM system at IGS-VAST.

Test methods to determine physicomechanical properties of samples:

- Bulk density (the Vietnamese standard of TCVN: 250-1986);

- Water absorption (the Vietnamesestandard of TCVN: 248-1986);

- Water-resistance (the Vietnamese standard of TCVN: 3735-1982);

- Compressive strength (the Vietnamese standard of TCVN: 246-1986).

The method was performed at IGS-VAST and the Hanoi University of Mining and Geology.

3. Results

3.1. Mineral component and chemical composition of Pha Lai fly ash

The mineral composition (wt%) of Pha Lai fly ash was mainly mullite (15-20%), quartz (14-16%), carbon (5-7%), and a small content of hematite. The content of the amorphous component in Pha Lai fly ash was about 67-73% (Nguyen A.D. et al., 2020). The existence of an amorphous component in Pha Lai fly ash was illustrated by a broad diffuse halo in the range of 20-30°2θ (Fig. 1). Under SEM, the amorphous component was spherical aluminosilicate particles with the size of 2-20μm (Fig.2).

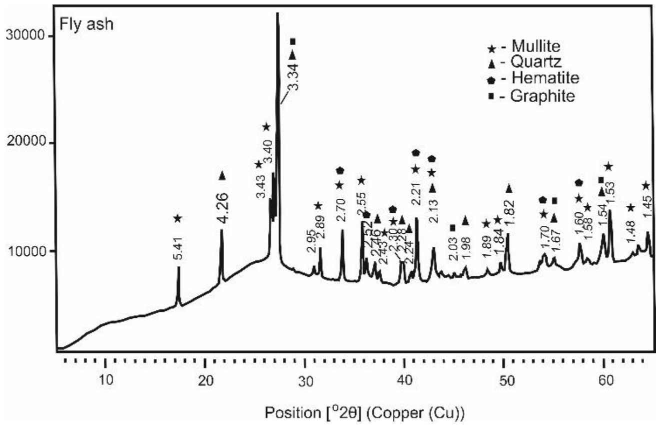


Figure 1. XRD phase of Pha Lai fly ash

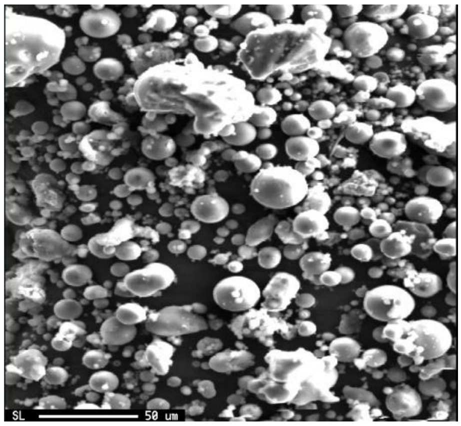


Figure 2. A SEM image of microstructure of Pha Lai fly ash

3.2. Physico-mechanical properties of lightweight materials fabricated in the form of the lime + pozzolan binder

Based on the principle of creating lime + pozzolan binders, the main material was Pha Lai fly ash; additives were hydrated lime, and cement, lightweight material products (Fig.3) were fabricated. Their physicomechanical properties were presented in table 3. According to this method, the products obtained the bulk density of 1.08-1.32 g/cm^3, the water absorption of 26.38-40.27%, the porosity of 35.55-68.91%, and the compressive strength of 0.91 -3,91Mpa. When the content of hydrated lime increased from 10% to 20%, there was a rise in the bulk density from 1.08 to 1.32 g/cm^3, the porosity decreased from 68.91% to 35.55%, and the water absorption also went up dramatically from 0.91 to 3.91MPa. To achieve a better adhesion property and increase the compressive strength of lightweight material samples, cement was added to the mixture. However, these samples became heavier than the samples without cement; the bulk density of the samples increased from 1.20 to 1.32 g/cm^3 when adding from 0% to 10% cement. However, their compressive strength only increased slightly. Therefore, mixing cement with the mixture to fabricate lightweight materials is lowly effective.

Figure 3. Lightweight materials were fabricated following the lime + pozzolan binder

Table 3. Physico-mechanical properties of lightweight materials fabricated in the form of the lime + pozzolan binder

Samples	Bulk density (g/cm^3)	Water absorption (%)	Porosity (%)	Compressive strength(MPa)
VL1	1.08	38.65	68.91	0.91
VL2	1.20	36.27	43.19	1.02
VL3	1.32	26.38	35.55	3.91
VL4	1.26	35.64	42.90	1.09
VL5	1.32	28.36	37.67	2.59
The Vietnamese standard TCVN: 6477-2011 for concrete brick	<1.65	6-18		3-20

3.3. Physico-mechanical properties of lightweight materials fabricated in the form of the geo-polymeric binder

By applying geopolymer technology, Pha Lai fly ash was mixed with NaOH/ Na_2SiO_3 solution, Al powder, cement, and water at different ratios (Table 2) to create lightweight materials shown in figure 4. The samples obtained the bulk density of 0.51-1.42 g/cm^3, the water absorption of 17.65-69.09%, the porosity of 38.25-76.24%, the compressive strength of 0.40-5.60 MPa (Table 4). At the different ratios of $NaOH/Na_2SiO_3$ solution, the lightweight materials had different bulk densities, porosity, water absorption, and compressive strength. For example, at the $NaOH/Na_2SiO_3$ ratio of 1:1, the lightweight material (sample GN1) had a bulk density of 0.68g/cm^3, the water absorption of 34.67%, the porosity of 66.62%, the compressive strength of 0.4Mpa. When increasing the $NaOH/Na_2SiO_3$ ratio to 1:2 (sample GN2) and 1:3 (sample GN3), the bulk density of these samples also increased to 0.70g/cm^3 and 0.84g/cm^3, respectively, the porosity and the water absorption decreased, and the compressive strength increased to 0.93MPa and 0.96Mpa, respectively. To obtain the goal of production of lightweight materials with a high compressive strength, the optimal ratio of $NaOH/Na_2SiO_3$ solution was 1:2.

The content of $NaOH/Na_2SiO_3$ solution was from 20-45wt% of the fly ash content. The amount of water was added to create the plasticity and the shape of materials.

With the $NaOH/Na_2SiO_3$ content of 20% (sample GN4), the sample had the bulk density of 1.01g/cm^3, the water absorption of 24.65%, the porosity of 44.07%, and the compressive strength of 0.89MPa. When the content of $NaOH/Na_2SiO_3$ solution increased to 25% (sample GN5), 30% (sample GN2), 35% (sample GN6), and 45% (sample GN7); the bulk density decreased to 0.73g/cm^3 (sample GN5), 0.70 g/cm^3 (sample GN2), and then slightly increased to 0.80 g/cm^3 (sample GN6), 0.86 g/cm^3 (sample GN7); the porosity increased from 44.07% (sample GN4) to 65.90% (sample GN7); the water absorption increased from 24.65% (sample GN4) to 30.2% (sample GN2), then declined to 26.89% (sample GN6) and 20.91% (sample GN7); the compressive strength increased from 0.89MPa (sample GN4) to 2.02MPa (sample GN7).

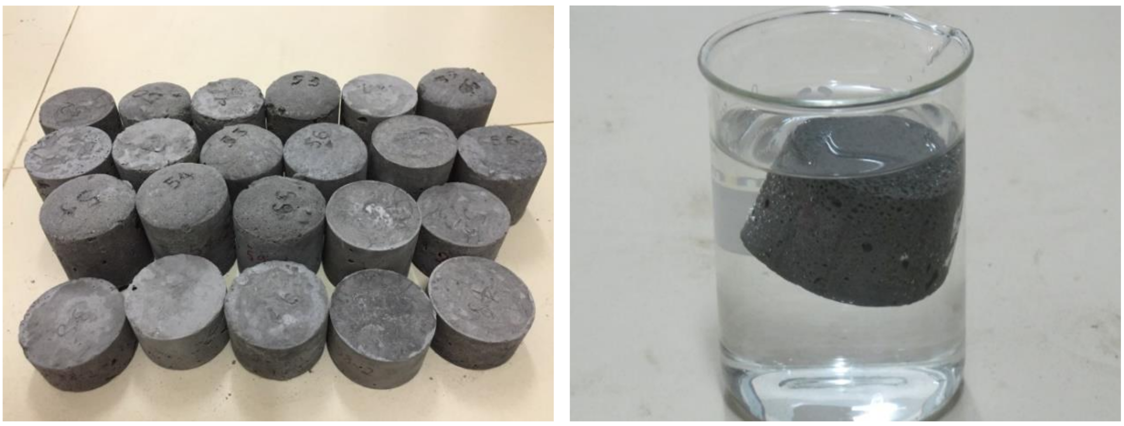
As a result, when increasing the content of $NaOH/Na_2SiO_3$ solution, a part of the NaOH solution will react with Al powder to form the porosity of lightweight material. Therefore, if the content of $NaOH/Na_2SiO_3$ solution is shallow, it will not be enough to create the geo-polymeric binder of the material, and the content of the NaOH solution will not be enough to react completely with Al powder, this is quite important to form the porosity of the material.

This explains why the samples that used the $NaOH/Na_2SiO_3$ solution (< 25%) have a high bulk density and low compressive strength. However, if the content of the alkaline activator solution is too high, the content of liquid sodium silicate solution (Na_2SiO_3) will increase. Moreover, the bulk density of this solution is quite high (1.4-1.5g/cm^3), which causes a rise in the bulk density of sample GN6 and sample GN7.

To increase the adhesion and the compressive strength of lightweight material samples, cement was mixed with the concentration of 5% (sample GN8) and 10% (sample GN9). Because of the increase of the cement content, the compressive strength also increased from 0.93MPa (sample GN2) to 0.95MPa (sample GN8) and 1.03MPa (sample GN9); however, the water absorption and the porosity was reduced, and the bulk density increased. This is caused by the high solidification rate and the high bulk density of cement.

To make air bubbles and create a pore structure for lightweight materials, Al powder was added to the mixture at different contents, including 0g (sample GN10); 0.05g (sample GN11); 0.1 (sample GN2); 0.15g (sample GN12); 0.2g (sample GN13). When the Al powder content increased, the bulk density of samples slightly decreased from 1.42 (sampleGN10) to 0.51g/cm^3 (sample GN13), the porosity increased from 38.25% (sample GN10) to 76.24% (sample GN13), the water absorption increased from 17.65% (sample GN10) to 69.09% (sample GN13), the compressive strength was reduced from 5.60MPa (sample GN10) to 0.50MPa (sample GN13). Therefore, for the samples with a high alkaline activator solution, a large amount of Al powder should be added to reduce their bulk density. However, to obtain high compressive strength, the content of Al powder is about 0.1-0.2g.

From the above result, it can be assumed that the appropriate mixing ratio for fabricating lightweight materials was fly ash: $NaOH/Na_2SiO_3$: Al powder: water = 100:30:0.1:15 (sample GN2). As a result, the sample had a bulk density of 0.70g/cm^3, a porosity of 62.08%, water absorption of 30.25%, compressive strength of 0.93MPa. However, to obtain high compressive strength and a low bulk density, sample GN14 with the mixing ratio of fly ash: $NaOH/Na_2SiO_3$: Al powder: = 100:45:0.15 was fabricated. As a result, the sample had a bulk density of 0.62g/cm^3, the water absorption of 58.68%, the porosity of 71.15%, and the compressive strength of 1.54MPa, satisfying the Vietnamese standard TCVN: 9029-2017 for lightweight concrete-foam concrete, non-autoclaved concrete products.



(a) (b)

Figure 4. Lightweight material samples fabricated from Pha Lai fly ash based on geopolymer technology; (a)- at different mixing ratios; (b)- sample GN14

Table 4. Physico-mechanical properties of lightweight samples fabricated by geopolymer technology

Samples	Bulk density (g/cm^3)	Water absorption (%)	Porosity (%)	Compressive strength (Mpa)
GN1	0.68	34.67	66.62	0.40
GN2	0.70	30.25	62.08	0.93
GN3	0.84	26.70	60.84	0.96
GN4	1.01	24.65	44.07	0.89
GN5	0.73	28.24	57.25	0.73
GN6	0.80	26.89	63.96	1.02
GN7	0.86	20.91	65.90	2.02
GN8	0.81	39.23	60.81	0.95
GN9	0.97	34.48	58.12	1.32
GN10	1.42	17.65	38.25	5.60
GN11	1.01	22.65	55.39	4.31
GN12	0.54	66.67	74.32	0.70
GN13	0.51	69.09	76.24	0.50
GN14	0.62	58.68	71.15	1.54
Bentonite-based lightweight material*	0.5-0.6	70	50-70	
Kaolin-based lightweight material*	0.6-0.7	75-80	55-60	0.9-1
Red basalt-based lightweight material*	0.6-0.65	80-85	55-65	0.98-1
Foam concrete - Institute of Concrete Technology	0.65-1.05			1-5
The Vietnamese standard TCVN: 9029-2017 for lightweight concrete-foam concrete, non-autoclaved concrete products	0.5-1.2			1.0-17.5

Note:""- Nguyen A.D., 2006.*

4. Discussions

Based on the principle of the manufacture of non-fired building materials, binders can bind the aggregates to form mechanical and chemical stability of the products. The commonly used binders are traditional binders such as portland cement and lime + pozzolan binder and geo-polymeric binder (Kieu Q.N & Nguyen A.D., 2015).

Raw minerals used for manufacturing non-fired building materials should contain a large number of amorphous components. These components are commonly colloidal silica and alumina. Under the high alkaline condition, they were activated to form binders for the products (Davidovits, 2011; Nguyen A.D et al., 2014; Kieu Q.N & Nguyen A.D, 2015). From the result of chemical composition and mineral component of Pha Lai fly ash, it can be seen that this waste byproduct of the thermal power plant contained a high content of amorphous components about 67-73%, the total content of Al_2O_3+ SiO_2+Fe_2O_3 was 79.18% which was larger than 70, other minerals were mullite (15-20%), quartz (14-16%), carbon (5-7%). Therefore, it can be concluded that amorphous components in Pha Lai fly ash were mainly amorphous Al_2O_3 and SiO_2. Moreover, Pha Lai fly ash had a density of 2.54 g/cm^3, comparing to other raw materials such as kaolin (2.58-2.6 g/cm^3) (Le D.T. et al., 2008), red basalt (2.75-2.91 g/cm^3) (Pham V.T., 1991), cement (3.05-3.15 g/cm^3), it is quite light. Thus, with these characteristics of

Pha Lai fly ash, we fabricated lightweight materials by two methods, including lime + pozzolan binder and geo-polymeric binder.

For lightweight materials fabricated by the method of lime + pozzolan binder, when Pha Lai fly ash is mixed with hydrated lime and water, amorphous Al_2O_3, SiO_2 components in the fly ash will participate in polycondensation reactions (1), (2), (3) to form CSH or CASH phases which can binder materials together (Bui V.C. and Dao T.D., 1986; Nguyen A.D. et al., 2014, 2020). These binders are amorphous or semi-crystalline under room conditions. This is illustrated in XRD patterns; a broad diffuse halo at the position of 17-30 °2θ in fly ash sample was shifted to the position of 18-35°2θ in the lightweight material (sample VL3) (Fig.5).

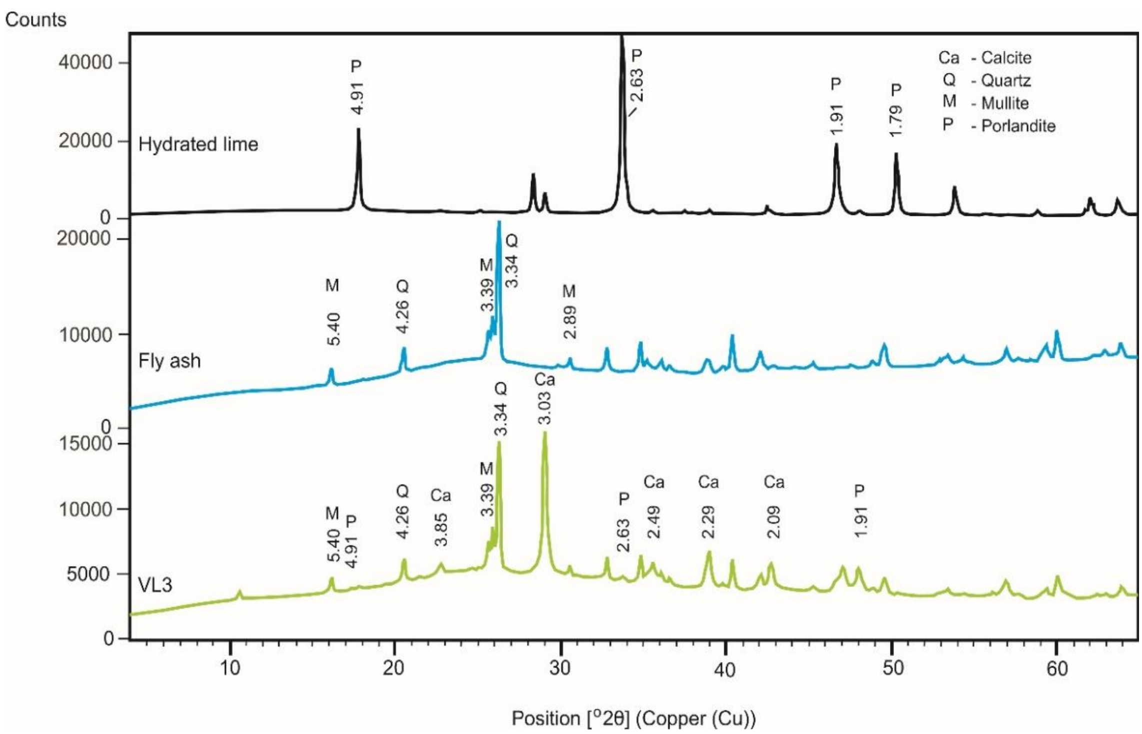


Figure 5. XRD patterns of hydrated lime, fly ash and a lightweight sample (VL3) fabricated by applying the fly ash + hydrated lime

In addition, a part of $Ca(OH)_2$ reacted with CO_2 in the air to form calcite following the reaction (4). This phase also made a rise in the compressive strength of the lightweight samples. In the XRD patterns, main peaks of calcite (d = 3.03, 29.44 °2θ; d = 2.49, 36.02 °2θ; d = 2.29, 39.46 °2θ; d=2.09, 43.22°2θ) were observed clearly.

$nSiO_2+Ca(OH)_2 \rightarrow nCaO.SiO_2.xH_2O$ (CSH) (1)

$nAl_2O_3+ Ca(OH)_2 \rightarrow nCaO.Al_2O_3.xH_2O$ (CAH) (2)

$nCaO.Al_2O_3.xH_2O+SiO_2 \rightarrow nCaO.Al_2O_3.SiO_2.xH_2O$ (CASH) (3)

$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O$ (4)

By applying the lime + pozzolan method, the building material products manufactured from fly ash had a bulk density of 1.08-1.32g/cm^3. Thus, they are much lighter than other non-fired building materials such as kaolin-based non-fired building material

(1.54-1.69g/cm^3) (Tran T.L., 2019), red basaltic soil-based non-fired building material (1.58g/cm^3) (Nguyen A.D et al., 2014), felsic volcanic rock-based non-fired building material (1.61-1.65g/cm^3) (Tran T.L. et al., 2019).

This is the outstanding advantage of the products because lightweight materials in the construction will reduce their load. However, the bulk density of these products is lighter; their porosity is higher. This causes an increase in their water absorption. According to ASTM C62 for building brick, ASTM C216 for facing brick, ASTM C902 for pedestrian and light traffic paving brick, bricks using negligible or weathering conditions are no limit in water absorption. The lightweight materials with high porosity usually have a good sound and thermal insulation. Moreover, the lightweight material products (VL4 sample) obtained the compressive strength of 3.91 MPa, satisfied the Vietnamese standard TCVN: 6477-2011 for concrete brick. Therefore, the lightweight materials manufactured from fly ash by applying this method can be used as facing bricks or building bricks which are good for houses about sound and thermal insulation.

For lightweight materials fabricated by applying geopolymer technology, when fly ash was mixed with the alkaline activators of NaOH and Na_2SiO_3, amorphous silica and alumina were dissolved and formed (Na,K)-Poly(siala-siloxo) geopolymers. The process of dissolution and polymerization of the fly ash occurred following the below reactions (5), (6), (7), (8) (Davidovit, 2011; Kieu Q.N.& Nguyen A.D., 2015):

$$SiO_2 + OH^- + H_2O \rightarrow {}^-OSi(OH)_3 \quad (5)$$

$$Al_2O_3 + OH^- + H_2O \rightarrow Al(OH)_4^- \quad (6)$$

$$(Na,K)^+ + {}^-OSi(OH)_3 \rightarrow (Na,K)^+OSi(OH)_3^- \quad (7)$$

$$(Na,K)^+ + Al(OH)_4^- \rightarrow (Na,K)^+Al(OH)_4^- + H_2O \quad (8)$$

Like other binders, geo-polymeric binders hardens at room temperature and mainly exist in the amorphous state. A broad diffuse halo identified them at a position range of 22-34 °2θ in the X-ray diffractograms (Davidovits, 2011). The evidence for forming the amorphous geo-polymeric components in the lightweight materials fabricated from Pha Lai fly ash by the geopolymer technology is a broad diffuse halo at the position of 20-34 °2θ in the X-ray diffractogram of GN14 sample (Fig.6). These components are the main phases that bound the aggregates to form compressive strength for the lightweight materials. In addition, the result of XRD analysis also illustrated the complete reactions of fly ash and NaOH/Na_2SiO_3 solution, of Al powder and NaOH, because of the disappearance of main peaks of Al powder, NaOH, Na_2SiO_3 in the XRD phase of the lightweight material sample (GN14) (Fig.6).

For lightweight geopolymer materials, Al powder was added to create the porosity of the materials and help them become more porous and lighter. This is based on the principle of the reaction (9). Thus, 1gram of Al powder will react with NaOH solution to produce about 1250cm^3 of hydrogen. This gas generated in the volume of a viscous, flexible mixture of aggregates will swell out the material. Therefore, it created a porous structure for the lightweight material.

$$2Al + 2NaOH + 2H_2O \rightarrow 2NaAlO_2 + 3H_2 \quad (9)$$

According to this method, with Pha Lai fly ash as the main raw material, lightweight materials were fabricated. They had a low bulk density from 0.62 g/cm^3 (GN14 sample) to 0.7g/cm^3 (GN2 sample), compressive strength from 0.93 MPa (GN2 sample) to 1.54MPa (GN14 sample). Comparing to other lightweight materials, which were produced from bentonite, kaolin, or red basaltic soils, and commercial foam concrete, Pha Lai fly ash-based lightweight materials have similar properties (Table 4), especially, GN14 sample totally satisfied the Vietnamese standard TCVN: 9029-2017 for lightweight concrete-foam concrete, non-autoclaved concrete products. Furthermore, one of the advantages of Pha Lai fly ash-based lightweight geopolymer materials is the high porosity (62.08-71.15%) and low absorption water (30.25-58.68%) (For example, GN2 sample and GN14 sample). This proves that the generated pores in these materials include both open and closed pores. This is a useful factor for these materials to use as sound and thermal insulation materials.

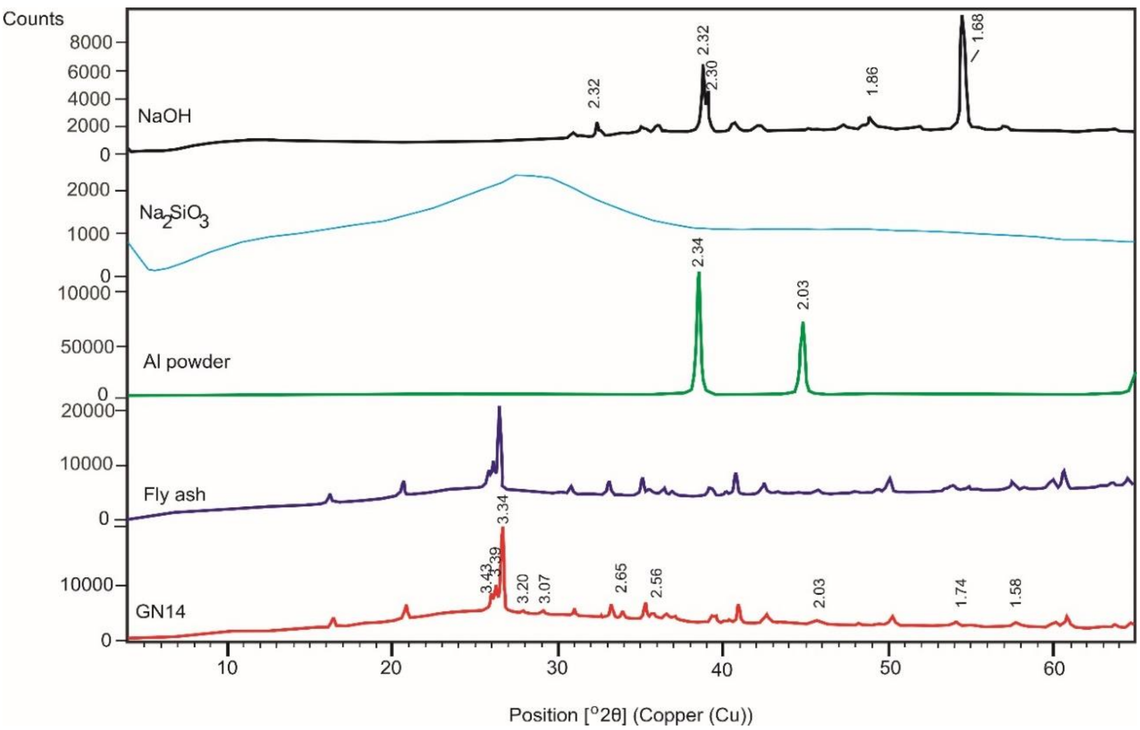


Figure 6. XRD patterns of Pha Lai fly ash, lightweight material (GN14), Al powder, Na_2SiO_3, NaOH

5. Conclusions

During the testing process of manufacturing Pha Lai fly ash-based lightweight building materials, some conclusions were given as follow:

(1) Pha Lai fly ash in which the main mineral component was quartz, mullite, carbon, and few hematites; the chemical composition was mainly Al_2O_3, SiO_2, Fe_2O_3, with the total content of ≈ 80%; the amorphous Al_2O_3 and SiO_2 content was about 67-73%, can use for the production of lightweight materials.

(2) Lightweight materials were fabricated by 2 methods: the method (1) - Lime + pozzolan binder, with the optimal ratio of fly ash: lime: water = 10:2:1 (VL3 sample), the products obtained the bulk density of 1.32g/cm^3, the compressive strength of 3.91MPa, satisfied the Vietnamese standard TCVN: 6477-2011 for concrete brick; the method (2) - geo-polymeric binder, with the optimal ratio of fly ash: $NaOH/Na_2SiO_3$: Al powder = 100:45:0.15 (GN14 sample), $NaOH/Na_2SiO_3$ ratio = 1:2, the product had the bulk density of 0.62g/cm^3, the compressive strength of 1.54MPa, total satisfied the Vietnamese standard TCVN: 9029-2017 for lightweight concrete-foam concrete, non-autoclaved concrete products.

(3) Fly ash is a raw material with a low density, so using this waste byproduct to produce lightweight building materials will increase its value. A study on using Pha Lai fly ash for fabricating lightweight materials has only been carried out at the laboratory. To complete the technological process and improve the product quality, detailed studies with the larger scale production should be performed.

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