Influence of Fly Ash and Recycled AAC Waste for Replacement of Natural Sand in Manufacture of Autoclaved Aerated Concrete

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Abstract. Currently in Vietnam, the source of natural sand used in construction in general and in production of autoclaved aerated concrete (AAC) in particular is increasingly exhausting, so finding new sources of raw materials to replace natural sand has important role to ensure the maintenance of construction material production activities as well as towards sustainable construction development. Autoclaved aerated concrete (AAC) is one of the lightweight concretes that commonly used in construction. AAC is relatively light in weight, having lower thermal conductivity, higher heat resistance, lower shrinkage, and faster in construction process when compared to the conventional concretes. This paper aims to research, use and compare the use of recycled AAC waste and fly ash to replace natural sand in AAC concrete brick production factory. The new developed AAC was conducted by replacing sand with recycled AAC and fly ash in ratio of 0%, 5%, 10%, 15%, 20%, 30%, 40% and 60, 80 and 100%. Mechanical tests such as density, compressive strength have been carried out. Research results show that it is possible to take advantage of recycled AAC waste products with a maximum content of 5% and fly ash with a content of up to 100% to replace the natural sand in the manufacture of AAC bricks. In terms of economic and technical efficiency, the use of fly ash is more optimal, because it allows reducing the volumetric density, enhancing compressive strength and minimizing the grinding cost as well as contributing to environmental protection, aiming to sustainable construction.

1. Introduction
Autoclaved aerated concrete (AAC) is a lightweight cellular concrete that has been used for more than 80 years. Currently, however, no good recycling options for AAC from construction and demolition waste exist. The amount of AAC waste that can be recycled in the production of new AAC is limited because of quality issues. Autoclaved aerated concrete brick (AAC) products are now widely used in Vietnam and around the world thanks to their advantages such as lightweight, sound insulation, thermal insulation, shock resistance. Good performance, high accuracy, friendly with environment, saving construction cost. This type of concrete contains a large volume of small and tight artificial pores in spherical shape containing gas or a gas-steam mixture, sized from 0.5 to 2.0 mm, distributed in evenly way and separated by thin, firm walls [1, 2]. Currently in Vietnam, the source of natural sand used in construction in general and in production of autoclaved aerated concrete (AAC) in particular is increasingly exhausting, so finding new sources of raw materials to replace natural sand has important role to ensure the maintenance of construction material production activities as well as towards sustainable construction development [3]. On the other hand, in the process of AAC brick production in Vietnam, due to the lack of modern production technology, the amount of waste products is still high, wasting factory space, decreasing the beauty of the factory and affecting the manufacturing...
environment. Therefore, taking advantage of this type of industrial waste to put into production of AAC concrete bricks is extremely urgent [4, 5].

In autoclaved aerated concrete production line, waste is mainly generated from two main stages: after cutting and after-autoclave process [6, 7]. Waste after the cutting process will be recovered by the tank placed under cutter machine to make the after-cutting screed and be utilized in the next moulding process. However, the remaining waste, which appears after the autoclaved process, are cracked, must be eliminated [8, 9]. This amount of waste does not meet the Vietnamese standards TCVN 7959 - 2011 or according to the factory standard [10]. Post-autoclave waste is a form of autoclaved aerated concrete that has strength and physical properties as the final product. Autoclaved aerated concrete waste is due to undergoing hydration processes, the microstructure of the waste also contains large amounts of Tobermorite minerals (\(\text{C}_6\text{Si}_6\text{H}_6\)) formed under conditions 175 - 195˚C and a quantity of Xonolite mineral (\(\text{C}_6\text{Si}_6\text{H}\)). These two minerals are formed in the autoclave process, which plays a major role in the compressive strength of the product, so when putting the autoclaved aerated concrete waste into production, it can increases the content of minerals, which affects the compressive strength of autoclaved aerated concrete products [2, 11, 12].

To provide additional silicon components in aerated concrete, in addition to quartz sand, thermal fly ash is also commonly used. Fly ash is a by-product of coal combustion in thermal power plants. The amount, type, fineness and unburnt coal content of this silica component have a significant effect on the strength of AAC concrete [13, 14]. Currently, due to the increasing demand for electricity, many thermal power plants are built and put into operation, so the amount of fly ash emitted is very large and causes many environmental impacts. The use of fly ash in AAC aerated concrete indirectly protects the environment by being able to take advantage of this waste source and can reduce the amount of cement and sand used in concrete thereby significantly reducing CO$_2$ emissions to the environment and can protect natural resources [15]. For the above reasons, the utilization of autoclaved aerated concrete waste and fly ash in production to replace a content of natural sand, contributing to saving production costs and protecting the environment is an urgent requirement.

2. Materials and methods

2.1. Materials

2.1.1. Cement: In this study, cement Xuan Thanh PC40 was used. Some technical properties of this cement were shown in Table 1 as follows:

| Properties                        | Unit      | Results | Experimental Method |
|-----------------------------------|-----------|---------|---------------------|
| Fineness                          |           |         |                     |
| - Amount retained on 0.09 mm sieve| %         | 5.8     | TCVN 4030:2003      |
| - Fineness (Blaine)               | cm$^2$/g  | 3460    |                     |
| Standard Consistency              | %         | 28.5    | TCVN 6017:2015      |
| Soundness                         | mm        | 0.8     | TCVN 6017:2015      |
| Density                           | g/cm$^3$  | 3.10    | TCVN 4030:2003      |
| Setting time                      |           |         |                     |
| - Initial                         | min       | 110     | TCVN 6017:2015      |
| - Final                           | min       | 166     |                     |
| Compressive Strength              |           |         |                     |
| - 3 days                          | MPa       | 24.6    | TCVN 6016:2011      |
| - 28 days                         | MPa       | 47.6    |                     |

2.1.2. Quick lime. Some technical properties of quick lime are shown in Table 2 as follows:
### Table 2. Technical properties of quick lime used in research

| №  | Characteristic          | Unit | Result |
|----|-------------------------|------|--------|
| 1  | Slaking speed           | min  | 12     |
| 2  | Slaking temperature     | °C   | 80.4   |
| 3  | Amount retained on 0.09 mm sieve | % | 9      |

2.1.3. *Ground sand.* The ground sand used in the production of autoclaved aerated concrete is quartz sand with a SiO₂ content above 94% and Amount retained on 0.09 mm sieve below 14.5%

2.1.4. *Gypsum.* It is used to control the setting time and hardening process of semi-finished product. The gypsum in the study has an amount of SO₃ is 43.9%, and Amount retained on 0.09 mm sieve is 9.6%

2.1.5. *Gas generator.* Gas generator for AAC production is aluminum powder, with the Active aluminum content of 95% and reaction rate of 21 minutes.

2.1.6. *Water.* Water used in this research meets TCVN 4056 - 2012 for water used in manufacturing mortar and concrete in construction.

2.1.7. *Recycled AAC waste.* The waste used in the study is AAC waste collected from AAC Viglacera Yen Phong Bac Ninh factory, finely ground to a fineness (the amount of residues on a sieve with a sieve size of 0.09mm does not exceed 14%) is equivalent to the fineness of the sand. The waste in the study is shown in Table 3 as follows:

### Table 3. Chemical composition of autoclaved aerated concrete waste - Viglacera

| Oxide | SiO₂ | Al₂O₃ | Fe₂O₃ | CaO  | MgO  | Na₂O | K₂O | SO₃ | MKN  |
|-------|------|-------|-------|------|------|------|-----|-----|------|
| Content, % | 57.09 | 3.82  | 2.02  | 22.78 | 1.57 | 0.08 | 0.90 | -   | 9.30 |

2.1.8. *Fly ash.* When using fly ash as a silica component in autoclaved aerated concrete, the criteria for SiO₂ content, fineness and unburnt coal content should be considered. This study uses fly ash type F of Pha Lai thermal power, with moisture ≤ 3%, fineness 3000 - 4000 cm²/g. The fly ash studied used has the chemical properties shown in the table 4:

### Table 4. Technical properties of Fly ash

| Oxide | SiO₂ | Al₂O₃ | Fe₂O₃ | CaO  | MgO  | Na₂O | K₂O | SO₃ | MKN  |
|-------|------|-------|-------|------|------|------|-----|-----|------|
| Content, % | 58.1  | 25.3  | 7.8   | 0.6  | 1.1  | 0.4  | 4.3 | 0.05 | 6.0  |

2.2. *Method*

This article uses Vietnamese standards to test properties and evaluate performance of materials used in the research. The standard TCVN 7959 - 2011 was used to test and evaluate important properties of AAC concrete such as volume density and compressive strength.

2.3. *Autoclaved aerated concrete formulation*

This study selected AAC concrete with a designed volume density of 600 kg/m³, after adjusting the mix proportion according to the survey results; the formulation is selected specifically in the table 5 as follows:
## Table 5. Formulation calculated for 1000 liter of AAC

| Materials          | Cement (kg) | Quick lime (kg) | Ground Sand (kg) | Water (kg) | Al powder (kg) | Gypsum (kg) |
|--------------------|-------------|-----------------|------------------|------------|---------------|-------------|
| Vbatch = 1000 liters | 109.32      | 60.73           | 380.91           | 341.59     | 0.43          | 19.05       |

2.4. Mixing and casting process

The mixture of ground sand, ground waste AAC, cement, gypsum and water after blending was mixed for 2 minutes, then quick lime was added and stirred for 5 minutes. After that, aluminium powder was added and mixed for 1 minute. The fresh AAC mixture was then poured into the mould, gently shaking the mould to release large air bubbles due to the pouring of the sample into the mould. Store samples after pouring in the room at a temperature of 20-25°C for 1 day, then transfer the sample to autoclave with a temperature of 190 – 195°C, a pressure of 12 atm for 12 hours. After autoclaving, it is necessary to dry samples at a temperature of 100 ÷ 105°C and carried out the determination of parameters such as compressive strength, volumetric density according to TCVN 7959: 2011.

### 3. Research results

#### 3.1. Influence of partial replacement of ground sand with recycled AAC waste to compressive strength and volume density of AAC

Experimental results of the influence of replacing partially ground natural sand with AAC waste to the volume density and compressive strength of AAC concrete are shown in the Table 6:

| Replacement content of sand by AAC waste, % | Dry volume density (kg/m³) | Compressive strength (Mpa) |
|--------------------------------------------|----------------------------|-----------------------------|
| 0                                          | 617                        | 3.53                        |
| 5                                          | 620.7                      | 3.48                        |
| 10                                         | 625.2                      | 3.25                        |
| 15                                         | 629.1                      | 3.16                        |
| 20                                         | 633.4                      | 3.09                        |
| 30                                         | 642.8                      | 2.95                        |
| 40                                         | 657.1                      | 2.83                        |
| 60                                         | 664.9                      | 2.41                        |
| 80                                         | 677.2                      | 1.81                        |
| 100                                        | 690.9                      | 0.79                        |
The results in Figures 1&2 indicate that when increasing the partial replacement of ground sand with AAC waste content of 0% to 100%, the dry volume density of the sample gradually increases. However, the increase of this parameter is not very significant. The sample replace up to 100% of ground sand with AAC waste has highest volume density, which is only higher 11.99% when compared to the control sample (100% natural sand). As the proportion of AAC waste replacing ground sand increases, the compressive strength decreases. In this case, difference of the compressive strength is quite clear. The compressive strength of the sample using 5% AAC waste is reduced only 1.42% when compared to the control sample. However, The reduction of compressive strength increase to 76.63% when replacing 100% ground sand by AAC waste. Thus, it can be seen that the use of AAC waste substituting for sand is inefficient when used in large quantities.

3.2. The influence of partial replacement of ground sand with fly ash on the compressive strength and volume density of AAC blocks.

Experimental results of volume density and compressive strength of aerated concrete using fly ash to replace partially ground sand are shown in Table 7 as follows:

![Figure 1. Relationship between AAC waste content and dry volumic density of autoclaved aerated concrete](image1)

![Figure 2. Relationship between AAC waste content and dry compressive strength of autoclaved aerated concrete](image2)
Table 7. Test results of volumetric density and compressive strength of autoclaved aerated concrete

| Replacement content of sand with AAC waste, % | Dry volume density (kg/m$^3$) | Compressive strength (Mpa) |
|-----------------------------------------------|-------------------------------|---------------------------|
| 0                                             | 617.0                         | 3.53                      |
| 5                                             | 614.5                         | 3.55                      |
| 10                                            | 613.2                         | 3.57                      |
| 15                                            | 611.2                         | 3.59                      |
| 20                                            | 609.7                         | 3.65                      |
| 30                                            | 606.8                         | 3.77                      |
| 40                                            | 605.7                         | 3.85                      |
| 60                                            | 592.4                         | 4.02                      |
| 80                                            | 583.4                         | 3.93                      |
| 100                                           | 562.7                         | 3.76                      |

Figure 3. Relationship between fly ash content and dry volume density of autoclaved aerated concrete blocks.
Through the obtained results in Table 7 and Figures 3 & 4, it can be seen that when replacing ground sand with fly ash of 0%, 5%, 10%, 15%, 20%, 30%, 40%, 60%, 80%, 100%, the dry volume density of autoclaved aerated concrete samples tends to be the opposite of the case of replacement by AAC waste. It means the volume density of aerated concrete samples decreases with an slightly increasing fly ash content. The sample with the lowest volume density was the sample replacing 5% ground sand with fly ash: a decrease of 0.41% compared to the control sample; the sample with the most reducing volume density is the sample using fly ash to replace 100% ground sand with a decrease of 8.79% compared to the control sample M6. Regarding compressive strength: the greater the replacement of ground sand with fly ash, the higher the compressive strength is. An slight increase of 0.85% when replacing by 5% fly ash, and the highest compressive strength is the sample using 60% fly ash as a substitute for sand in the mixture. In this case, an increase of 14.2% when compared to the control sample is observed. Through the results of sections 3.1 and 3.2, it is possible to compare the influence of replacing a part of ground sand with recycled AAC waste and with fly ash to the compressive strength and volume density of autoclaved aerated concrete through Figure 5 as follows:
Figure 5. Comparing the effect of replacing a part of ground natural sand with aerated concrete waste and fly ash to the compressive strength and volume density of autoclaved aerated concrete blocks.

Through the comparison results in Figure 5, it can be seen the important results. With the use of AAC waste about 5%, the volume density and the compressive strength of concrete brick products are not much different from the control samples. According to the data survey on actual production of autoclaved aerated concrete at some factories in Vietnam, the amount of waste products does not exceed 4-5% of the actual production volume, the AAC plants can take recycle all waste products in the production process, but do not affect the quality of AAC blocks. For fly ash, the results showed the ability to replace completely ground sand with fly ash in the making of AAC. The use of fly ash brings two basic benefits: improving compressive strength, reducing energy efficiency. Research results also show that fly ash content replacing ground sand of about 60% will give optimal compressive strength, but replacing 100% sand with fly ash also results better than the control sample using 100% sand. This will both ensure technical benefits, tremendous economic and environmental benefits, contribute to solving environmental problems for current thermal power plants in Vietnam.

4. Conclusion
Based on the research results, some important conclusions can be drawn as follows:
- When using autoclaved aerated concrete waste instead of ground natural sand, the compressive strength of sample decreases, but the volume density increases with the replacement content. The content of AAC waste replacing natural sand in the production of AAC concrete is recommended below 5%.
- Conversely, when using fly ash for replacing ground natural sand, the compressive strength of the sample increases; the optimal replacement amount is 60% of fly ash. On the other hand, the use of fly ash also allows reducing the bulk volume density of the product.
- The use of AAC waste and fly ash will contribute to solving environmental problems at AAC factories, at thermal power plants as well as reducing product costs, making an important contribution to the strategy for developing and using non-fired building materials and fly ash in Vietnam.

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