International Journal of GEOMATE, Feb., 2021, Vol.20, Issue 78, pp. 128-134
ISSN: 2186-2982 (P), 2186-2990 (O), Japan, DOI: https://doi.org/10.21660/2021.78.j2048
Geotechnique, Construction Materials and Environment

RECYCLING OF AAC WASTE IN THE MANUFACTURE OF AUTOCLAVED AERATED CONCRETE IN VIETNAM

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ABSTRACT: The use of recycled materials helps investors to save significantly on production costs, not only from raw material extraction cost but also in the production process. Especially, recycling waste materials helps reducing energy, fuel, and labor costs. Besides, the transportation of recycled materials is also less expensive than the transportation of raw materials. The workload involved in the recycling of materials is minimal but with economic and technical efficiency. Autoclaved aerated concrete (ACC - Autoclaved aerated concrete) has been widely applied in construction works in Vietnam and is considered a reasonable replacement of fired bricks due to lower volume density, and better soundproofing - insulation. The main materials used to make AAC concrete include ground quartz sand, cement, lime, gypsum, aluminum powder, and some other technological additives. However, due to the depletion of natural sand, the partial or complete replacement of natural sand in AAC concrete production plays an important signification. In this study, the AAC waste after the autoclaving process was reused to replace the ground natural sand. The research results show that the AAC waste bricks could be reused with a content of up to 25% to replace the natural sand in AAC fabrication. The main properties of products such as compressive strength, bulk volume density, and drying shrinkage meet the technical requirements of ASTM C1693.

Keywords: Autoclaved Aerated Concrete, AAC waste, Compressive strength, Drying shrinkage.

1. INTRODUCTION

Currently, the replacement and reduction of the use of natural materials in particular, aiming to make use of waste will meet the demand of developing construction materials in the future, contributing to protecting the environment and natural resources [1-3]. In Vietnam, there have been many studies on reuse of waste such as construction waste, industrial waste, etc. in the manufacture of unburnt building materials according to the government's development strategy [4-6]. One of the important materials targeted by the government is Autoclaved aerated concrete (AAC). The ACC has been widely applied in construction works and is considered a reasonable replacement of fired materials [7,8]. Autoclaved aerated concrete bricks, which have good sound and thermal insulation properties, have a weight of 30-50% lighter than fired bricks and only account for 25% of the weight of conventional concrete bricks. Building using this brick can save up to 40% of electricity from running an air conditioner [9]. To make this concrete, the main materials include finely ground quartz sand, cement, lime, gypsum, aluminum powder and some other technological additives. In particular, natural sand is purchased by factories from different sources, so the quality is not stable. In addition, when the source of natural sand is increasingly exhausted, the issue of using another material to replace part or the entire natural sands in AAC concrete production plays an extremely urgent role [10]. On the other hand, in the process of producing AAC bricks in Vietnam, due to the lack of modern production technology, the amount of waste products is still high (3-5%) [11], causing waste of space and losing the beauty of the factory.

The AAC waste products at autoclaved concrete factory are mainly generated from two main stages: after cutting and after autoclaving process [12,13]. Waste from the cutting process will be recovered to return to the mixing tank. The residues after the steaming process are cracked products, which must be removed [14] .... because they do not meet the technical requirements of Vietnam standard TCVN 7959 – 2011 [15] or according to specific standards of each factory. This amount of waste can now be used to dry mortar for construction or site levelling. However, due to porous hollow characteristics, levelling or plastering can be risky, do not guarantee technical specifications, consume a lot of labour, machinery and funding [16].

In addition, the use of AAC waste in manufacturing autoclaved aerated concrete also indirectly protects the environment, reduces CO_2 emissions and saves natural resources by reducing the amount of cement and finely ground natural sand [17]. However, autoclaved aerated concrete waste has some influence on the technical properties of AAC concrete [18-19], so it is necessary to have research to choose the right amount to reuse. Autoclaved aerated concrete waste is inert because it has undergone hydration processes, the microstructure of the waste also contains a large amount of Tobermorite minerals ($C_5S_6H_6$) formed at 175 - 195°C and an amount of Xonolite (C6S6H). The two above minerals are formed during autoclave process. In addition, Tobermorite ($C_5S_6H_6$) plays a major role to the compressive strength of the product, so when recycling the autoclaved aerated concrete waste into the production process, the content of these two minerals above can be increased and induced a good effect on the compressive strength of autoclaved aerated concrete products. Therefore, the utilization of autoclaved aerated concrete waste in production to replace a content of crushed sand is necessary, contributing to saving production costs and protecting the environment. For these reasons, the study on recycling the waste AAC products to replace natural sand in the production of autoclaved aerated concrete is an urgent problem, contributing to saving production costs and protecting the environment.

2. MATERIALS AND METHODS

2.1 Materials

To make autoclaved aerated concrete, the main materials used in this study are PC40 cement, AAC waste products, gypsum, quicklime, ground natural sand, aluminum powder. The chemical composition of some raw materials is shown in the Table 1.

Table 1 Chemical composition of materials used in the research

Chemical composition, % by weight	Materials		
	Cement	Natural sand	AAC waste
SiO_2	22.58	94.18	57.09
Fe_2O_3	3.43	0.80	2.02
Al_2O_3	4.63	2.76	3.82
CaO	65.24	1.33	22.78
MgO	1.31	0.35	1.57
Na_2O	-	-	0.08
K_2O	-	-	0.90
SO_3	2.0	-	-
TiO_2	-	-	-
L.O.I	1.83	1.25	9.30

2.1.1 Cement

In this study, cement Xuan Thanh PC40 was used. Some technical properties of this cement were shown in Table 2.

Table 2 Technical properties of cement used in the study

Properties	Unit	Results
Fineness		
- Retained percentage on 0.09 mm sieve	%	5.8
- Fineness (Blaine)	cm^2/g	3460
Standard Consistency	%	28.5
Soundness	mm	0.8
Density	g/cm^3	3.10
Setting time		
- Initial	min	110
- Final	min	166
Compressive Strength		
- 3 days	MPa	24.6
- 28 days	MPa	47.6

2.1.2 Quick lime

Some technical properties of quick lime are shown in Table 3 as follows:

Table 3 Technical properties of quick lime used in research

Characteristic	Result
Slaking speed	12 min
Slaking temperture	80.4 °C
Amount retained on 0.09 mm sieve	9 %

2.1.3 Ground natural sand

The ground sand used in the production of AAC is quartz sand with SiO_2 content above 94% and an amount retained on 0.09 mm sieve below 14.5%.

2.1.4 Gypsum

Gypsum is used to control the hardening process. The gypsum used in the study has the chemical composition presented in the Table 4.

Table 4 Chemical compositions of gypsum used in the experiment

Properties	Value, %
Amount of SO_3	43.9
Amount of MgO	1.4
Amount of ion Cl^-	0.04
Moisture	4.2
Amount retained on 0.09 mm sieve	9.6
Amount of chemical water	18.3

2.1.5 Gas generators

Gas generators for AAC production is aluminum powder with some properties presented in the Table 5.

Table 5 Properties of aluminum powder used in research

Properties	Value
Active Al content	95%
Amount retained on 0.09 mm sieve	1.4%
Reaction rate	Minutes

2.1.6. Water

The mixing water satisfies the technical requirements of the standard TCVN 4506 - 2012 [20] for the water used in producing concrete and mortar in construction.

2.1.7. Ground AAC Waste

The AAC waste used in the research (as shown in Fig. 1) was collected at the AAC Viglacera factory, Bac Ninh, Vietnam. It was finely ground until the residue mount on the sieve size of 0.09mm is less than 14% (equivalent to the fineness of ground natural sand) to facilitate the reaction in the autoclave process.

Fig.1 AAC waste used in the research

Fig.2 AAC waste used in the research

2.2 Methods

The study uses Vietnamese standards to test and evaluate the properties of the materials used. For important properties of AAC concrete such as volume density, compressive strength and drying shrinkage of the sample, the research uses ASTM C1693 "Standard Specification for Autoclaved Aerated Concrete" to check and evaluate [21]. In particular, the drying shrinkage of AAC bricks is a change in size when reducing the moisture, determined by measuring the change in length of the sample at 30% and 6% moisture. The apparatus used for measuring the drying shrinkage is shown in the Fig.3.

Fig.3 Apparatus Matest S.p.A Treviolo 24048 for testing dry shrinkage.

The drying shrinkage of a sample is determined by the following formula:

$\varepsilon = \varepsilon_6 - \varepsilon_{30}$

Where:

$\varepsilon 6$: length change at the moisture content of 6%, (in mm/m or %)

ε_{30}: length change at the moisture content of 30%, (in mm/m or %)

The measurement result is the average value of 3 samples.

2.3 Autoclaved Aerated Concrete Proportion

2.3.1. Original AAC mix proportion

This study aims to produce AAC - 2 grade concrete according to ASTM C1693 with the bulk volume density of 500 kg/m^3. The AAC mix proportion is in Table 6.

Table 6 Original mix proportion of AAC concrete with a mixing volume of 1000 liters

Cement (kg)	Quick lime (kg)	Ground Sand (kg)	Water (kg)	Al powder (kg)	Gypsum (kg)
91.1	50.6	317.4	289.3	0.51	15.9

2.3.2. Selecting the amount of ground AAC waste products replacing natural sand

The Table 7 presents the proportion of AAC waste products selected to replace natural sand by weight: 5%; 10%; 15%; 20%; 25%; 30%; 40%; 50%, 60%, 80%, 100%. The control sample contains 100% of natural sand (without AAC waste).

Table 7 Proportion of AAC waste replacing natural sand in the study

Amount of AAC waste products and Natural sand in mixture (%)		Remark
AAC Waste	Natural sand	
0%	100%	Control sample
5%	95%	
10%	90%	
15%	85%	
20%	80%	
25%	75%	
30%	70%	
40%	60%	
50%	50%	
60%	40%	
80%	20%	
100%	0%	

2.3.3. 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 10x10x10 cm as shown in Fig.4, 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 12atm 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 ASTM C1693.

Fig.4 Sample during volume expansion

3. RESULTS AND DISCUSSION

3.1 Effect of Partial Replacement of Ground Sand with Recycled AAC Waste to Compressive Strength and Volumetric Density of AAC

Experimental results of volumetric weight and compressive strength of autoclaved aerated concrete are presented in Table 8 and Fig.5.

Table 8 Test results of volumetric weight and compressive strength of autoclaved aerated concrete.

Content of AAC waste products replacing natural sand	Dry volume density (Kg/m^3)	Compressive strength, MPa
0%	540.52	3.46
5%	541.86	3.35
10%	541.93	3.29
15%	542.49	3.21
20%	543.69	3.06
25%	545.23	3.01
30%	547.10	2.85
40%	549.34	2.58
50%	552.25	2.44
60%	556.12	2.21
80%	560.90	1.78
100%	567.23	0.75

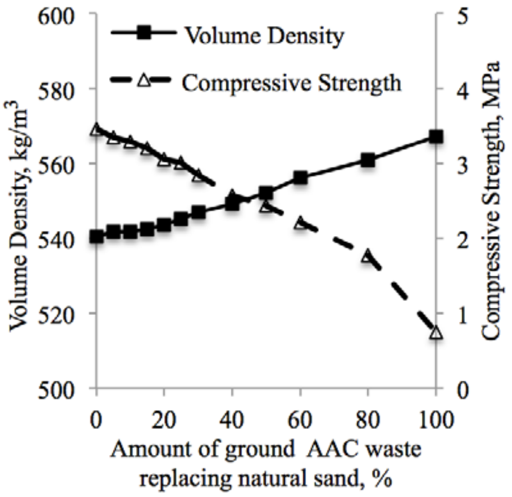

Fig.5 Effect of AAC waste ratio on compressive strength and Dry volume density of AAC

The results in Fig.5 show that when replacing a part of crushed sand with finely ground AAC brick waste, the dry volume weight of autoclaved aerated concrete sample tends to increase. However, if the replacement content is less than 20%, the volume weight of sample increases very little, almost negligible, only about 0.6%. When the content of AAC waste replacing natural sand increases by more than 20%, the volume weight tends to increase more strongly, but the maximum is 4.9% at 100% replacement of natural sand when compared to the control sample. Thus, it can be seen that replacing the natural sand with AAC waste product does not significantly change the volume weight of product. This can be explained by the fineness of natural sand and AAC waste, as well as the density of these materials is almost similar.

The results of compressive strength test of concrete also showed that the content of AAC waste products has a significant influence on the compressive strength of concrete. The test sample has the greater AAC waste sand content will have the smaller the compressive strength. Specifically, samples containing 100% AAC waste were reduced by 78.32% of compressive strength when compared to the control samples.

In production practice, to ensure aerated concrete with grade AAC-2 with nominal volume of 500kg/m^3 according to ASTM C1693 (minimum compressive strength of 2.0 MPa and volumetric density ranges from 450-550 kg/m^3, the study results suggest that only a maximum of 40% of AAC waste should be used to replace natural sand. However, through actual surveys of some AAC concrete factories in Vietnam, the percentage of waste products of the plants is relatively low, only about 2-4%. Therefore, the replacement of 5% of finely ground AAC waste in an AAC mixing batch will not affect the quality of the product.

3.2 Effect of Partial Replacement of Ground Sand with Recycled AAC Waste to Drying Shrinkage of AAC

The result of the drying shrinkage test of autoclaved aerated concrete samples with different ground AAC brick waste content is shown in Table 9 and Fig.6.

Table 9 Test results of drying shrinkage of autoclaved aerated concretes

Content of AAC waste products replacing natural sand	Drying shrinkage, %
0%	0.014
5%	0.015
10%	0.015
15%	0.016
20%	0.018
25%	0.020
30%	0.023
40%	0.024
50%	0.027
60%	0.029
80%	0.036
100%	0.038

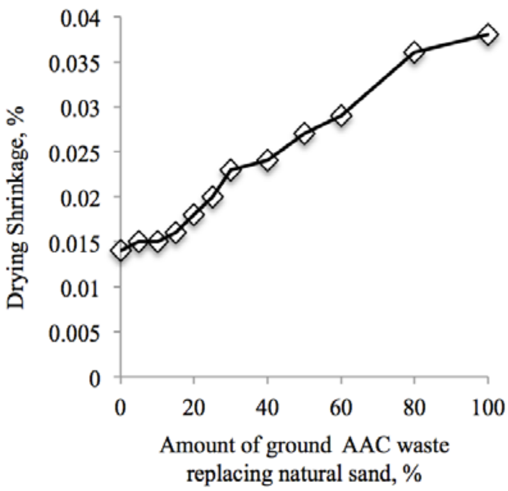

Fig.6 Shrinkage of autoclaved aerated concrete samples with different percentages of AAC waste

The drying shrinkage of samples in Fig.6 shows that the greater the content of AAC waste is finely ground, the greater the drying shrinkage is. With sand replacement content less than 15%, the shrinkage level is insignificant, about 0.015-0.016%, but when the replacement content is greater than 15%, the level of drying shrinkage increase quickly, can be up to 0.038% if completely replacing 100% natural sand by AAC waste. This can be explained by the fact that AAC waste products have a porous structure compared to finely ground natural sand (which can be considered as completely solid), so these samples are more likely to deform when absorbing moisture into the pores of concrete, this deformation is more evident when the content of replacement of AAC waste products is higher.

According to ASTM C1693, the shrinkage of autoclaved aerated concrete samples must not exceed 0.02%. Thus, it can be seen that if the content of AAC waste products replacing natural sand is less than 25%, the testing samples meet the requirement of drying shrinkage of this standard.

4. CONCLUSION

Based on the research results obtained, the study gives some conclusions and recommendations:

- It is possible to recycle AAC waste products to replace natural sand in manufacturing autoclaved aerated concrete in factories, contributing to reducing waste dump pressure, ventilating the factory landscape and partly reducing costs relating to increasing price of natural sand.
- When the content of AAC waste bricks replacing natural sand is higher, the volumetric density increases but the level is insignificantly. Meanwhile, the product compressive strength decreases quite quickly when the replacement content increases.
- The maximum ratio to make use of AAC waste bricks to replace crushed sand in autoclaved aerated concrete is 25%, but the actual rate at factories is 5%.

5. ACKNOWLEDGMENTS

The author would like to express my gratitude to the Hanoi University of Civil Engineering (Vietnam), The Vietnam National project "Promotion of Non-Fired Brick Production (NFB) Production and Utilization in Viet Nam " of UNDP and Bac Ninh AAC Viglacera Company for funding and experimental support.

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