Preparation of Autoclaved Aerated Concrete from Construction Waste

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Abstract. This research focuses on the preparation of autoclaved aerated concrete (AAC) with construction waste as the main raw materials. The properties of dry density and compressive strength of AAC were tested to determine the optimum mix proportion of raw materials and the construction waste fineness. The results indicated that the optimum mix proportion of raw materials was consist of 55-65% construction waste, 15-21% cement and 18-22% quicklime, together with 2% gypsum and 0.1% aluminum powder, the construction waste was mechanically milled for 20 min, and cured in the conditions of autoclave pressure 1.5 MPa for 6 h, the compressive strength of AAC samples were higher than 5.0 MPa, and dry density value could reach 650-700 Kg/m³, which meet the requirements of A5.0 B07 grade in the Autoclaved aerated concrete blocks (GB11968-2006). The analysis of microstructure and phase compositions of the AAC samples showed that the tobermorite, calcite and CSH were formed in the process of autoclave curing, and CSH gels were combined through the skeletons formed by tobermorite crystals, the interconnected and porous microstructure contributed to the good properties of low density and high strength of AAC.

1. Introduction

With the acceleration of the construction industry in China, a large amount of construction waste has been generated, most construction waste are piled up randomly or directly landfilled which have caused a serious of environmental and social problems. According to statistic, 30% to 40% of China's urban waste come from construction waste, the stockpiling amount of construction waste is 2.5×10^9 t, the total amount of construction waste generated is about 1.2×10^8 t per year and keep rising [1-3]. Therefore, in view of environmental protection and sustainable development, utilization of construction waste has become an urgent issue. Autoclaved aerated concrete (AAC) is a kind of lightweight, porous material with excellent thermal insulation properties that can be used to produce blocks, siding, floors, and roofing panels, which is usually produced through the process of molding and autoclaving with various raw materials. The commercialized AAC is usually produced with quartz sand or fly ash as siliceous materials, with cement and lime as calcareous materials, and small quantities of aluminum powder as foaming agent [4]. The advocating of Chinese government on building energy savings and cutting carbon emissions give autoclaved aerated concrete a broad
application prospect. In order to reduce production costs and save natural resources, many studies have focused on preparing AAC with industrial waste, such as fly ash, iron tailings, coal bottom ash, weathered sand, copper tailings and gold tailings [5-8]. However, there have been few studies of investigating the possibility of producing AAC from construction waste.

The objective of this study is to investigate the feasibility of producing AAC with construction waste. The influence of mix proportion and construction waste fineness on the AAC property was examined. Additionally, to make understanding of reaction mechanism, the microstructural and phase compositions of the AAC prepared by construction waste were investigated. The recycling of construction waste in producing AAC can not only reduce the exploitation and utilization of natural resources, but also achieve the recycling of secondary resources, which bring out economic and environmental benefits.

2. Material and methods

2.1. Raw materials

Raw materials contained construction waste, quicklime, cement, gypsum and aluminum powder. All the raw materials used were from the same batch to ensure the stability of the chemical compositions. The chemical components of raw materials are shown in Table 1.

| Component  | SiO₂  | Al₂O₃ | Fe₂O₃ | CaO  | MgO  | K₂O  | Na₂O  | TiO₂ | SO₃  | IL  |
|------------|-------|-------|-------|------|------|------|-------|------|------|-----|
| CW         | 48.29 | 6.15  | 3.64  | 25.81| 4.12 | 0.76 | 0.41  | 0.20 | 10.16|     |
| Quicklime  | 2.78  | 1.02  | 0.73  | 81.43| 1.45 | 0.13 | 0.18  | 0.33 | 11.16|     |
| Cement     | 17.76 | 6.83  | 4.04  | 64.62| 1.78 | 0.29 | 0.16  | 0.11 | 3.52 | 0.73|

Construction waste came from the demolished buildings in Wuhan, Hubei Province, which contains 48.29% SiO₂ and 25.81% CaO (Table 1), SiO₂ can replace traditional silicon material and CaO can also reduce the consumption of lime as a partial replacement of calcium resources. Further X-ray diffraction analysis of the construction waste used are revealed that the major mineral phases of the construction waste were quartz, calcite and dolomite, afwillite and tobermorite were the minor phase.

Quicklime contains 83.64% active CaO and the cement is commercial ordinary Portland cement 42.5 (P.O. 42.5), provided by Hubei Huaxin cement Co., Ltd. These three raw materials meet the basic requirements for the preparation of autoclaved aerated concrete and as the main source of siliceous and calcareous materials. The gypsum and aluminum powder were made by Sinopharm Chemical Reagent Co., Ltd, the aluminum powder had 80% solid content, 93% active Al content.

2.2. Procedure

The construction waste, quicklime, cement, gypsum and aluminum powder were weighed according to the proportions shown in Table 2, then the mixtures were placed into the cement mortar mixer to dry blend for 5 min, subsequently, added an appropriate amount of water and stirred for 20 min forming the primary slurry. Next, the obtained slurry was poured into a 40mm×40mm×40mm steel mold and precured at the temperature of 65°C for 4 h in an oven. After that, the expanded portions of samples were scraped off and remolded to obtain the green samples. Finally, the samples were placed into an autoclave at steam pressure of 1.5 MPa for 6h for hydrothermal reaction. The steamed samples were being naturally cooled and dried to get the final AAC samples.

2.3. Testing procedure

The dry density and compressive strength of AAC were tested according to Test methods of autoclaved aerated concrete (GB/T11969-2008). The chemical composition of raw materials was identified by Inductive Coupled Plasma Emission Spectrometer (ICP) (IRIS Advantage Radial). The materials particle distributions were detected by particle size analyzer (Marlvern Mastersizer 2000).
The raw materials specific surface area was detected by Micromeritics ASAP 2020. The mineralogical composition of the construction waste and AAC samples were determined through XRD (D/MX-III A). The microstructure of AAC samples were observed by SEM (PHILIPS XL30 TMP).

3. Results and discussion

3.1. Effects of the mix proportion of raw materials on the properties of AAC

The mix proportion of samples are presented in Table 2. Samples T1, T2, T3, T4, T5, T6 are set to investigate the effects of different admixing amounts of construction waste, quicklime and cement on the properties of AAC samples. The construction waste content varied between 45% and 70% by mass of dry mixtures, meanwhile, the cement content ranged from 27% to 12%, and the quicklime content changed from 26% to 16%. The percentage content of gypsum, aluminum powder and water in each dry mixture were constant, gypsum and aluminum powder were 2% and 0.1%, respectively, and water was 55% by mass of dry mixtures.

It is shown in table 2 that as the amount of construction waste increases, the strength of the AAC samples first increases and then decreases. When 60% construction waste, 20% lime and 18% cement was added, the highest compressive strength can reach 3.86 MPa, while the dry density change little and can be maintained the range of 700-750 Kg/m³. However, when the amount of construction waste is up to 70%, compressive strength is reduced to 3.31 MPa, this may be due to the fact that construction waste contains some inactive silicon and aluminum and does not form enough hydration products ensuring AAC strength [9,10]. Therefore, the optimum compositions should be addition of construction waste 55-65 %, together with cement 15-21 % and quicklime 18-22 %, the surfaces of samples were smooth and free of defects such as cracks.

| Sample number | CW (wt.%) | Cement (wt.%) | Quicklime (wt.%) | Gypsum (wt.%) | Aluminum powder (wt.%) | Water (wt.%) | Density (Kg/m³) | Compressive strength (MPa) |
|---------------|-----------|---------------|------------------|---------------|------------------------|-------------|-----------------|--------------------------|
| T1            | 45        | 27            | 26               | 2             | 0.1                    | 55          | 711             | 3.12                     |
| T2            | 50        | 24            | 24               | 2             | 0.1                    | 55          | 718             | 3.47                     |
| T3            | 55        | 21            | 22               | 2             | 0.1                    | 55          | 725             | 3.76                     |
| T4            | 60        | 18            | 20               | 2             | 0.1                    | 55          | 733             | 3.86                     |
| T5            | 65        | 15            | 18               | 2             | 0.1                    | 55          | 743             | 3.68                     |
| T6            | 70        | 12            | 16               | 2             | 0.1                    | 55          | 755             | 3.31                     |

3.2. Effects of mechanical milling time of construction waste on properties of AAC

The construction waste contains silicon and aluminum, but some are inactive. The mechanical milling is able to increase the content of disordered substances, activate silicon and aluminum in raw materials [11]. The construction waste were mechanically milled at a speed of 400 r/min for 0, 5, 10, 15, 20, 25, 30 min, and the construction waste with different particle size distributions were obtained. Under the conditions that construction waste 60%, cement 18%, quicklime 20%, gypsum 2%, and aluminum powder 0.1%, the influences of mechanical milling time on the properties of AAC samples are shown in Fig 1.
As shown in Fig 1., with the continuous increase of mechanical milling time, the compressive strength show initially rising and then declining, while the density reveal the opposite trend. When the milling time is 20min, the compressive strength and density have the optimum values of 5.12MPa and 696g/cm³, respectively. So the increasing of construction waste fineness can enhance the compressive strength efficiently, which mainly attribute to the higher reaction degree of silicon and aluminum with finer construction waste, so that more CSH and tobermorite could be formed during the autoclaving process [12,13]. However, as the mechanical milling time exceed to 20min, the compressive strength decrease and dry density of the sample increase.

The particle size D₉₀ and specific surface area of construction waste at different mechanical milling time are shown in Table 3. Table 3 shows that while the milling time prolong from 0 to 20 min, the particle size D₉₀ decrease from 18.676µm to 9.881µm, specific surface area increase from 5.4310m²/g to 6.8646 m²/g, further increase milling time, the particle size D₉₀ and specific surface area values change little as the mechanical milling time increase from 20 to 30 min.

Therefore, the milling time has an important effect on the particle size of construction waste. As the milling time increase from 0 to 20min, the obtained construction waste with the smaller particle size and the larger specific surface area, accordingly, inactive silicon and aluminum are further activated, the AAC with better performance can be prepared, when the milling time exceed 20min, the particle size and specific surface area are tending to be change little, but some finer particles agglomerate to increase the particle size, causing the decrease of silicon and aluminum reactivity and AAC performance, which is consistent with the experimental results (Fig 3.). Therefore, the optimum milling time is 20 minutes. Under these conditions the compressive strength and dry density of prepared AAC meet the requirements of A5.0 B07 grade in the Autoclaved aerated concrete blocks (GB11968-2006).

| Milling time | 0min | 10min | 20min | 30min |
|--------------|------|-------|-------|-------|
| D₉₀(µm)     | 18.676 | 14.989  | 9.881  | 9.776 |
| Surface Area (m²/g) | 5.4310 | 5.8853 | 6.8646 | 6.7768 |

3.3. XRD analysis
XRD analyses were performed to investigate the phase changes in the AAC samples. The XRD pattern of the AAC samples is shown in Fig 2. It indicates that the major mineral phases of the samples are tobermorite, calcite and CSH, the minor phases are quartz, dolomite, while afwillite existing in construction waste disappear. Tobermorite is the main hydration product evolved during the hydrothermal hardening of AAC, causing the high compressive strength of the final product, while CSH gel acts as a binder bonding all components in AAC together to form a good network that resists...

Fig 1. Effects of different mechanical milling time on properties of AAC samples
Fig 2. The XRD patterns of different mechanical milling AAC samples
stress concentration underloading [12-14]. In addition, Fig 2. shows that intensity of diffraction reflections of tobermorite increase with increasing milling time, it is probably ascribed to the finer construction waste resulted in higher reactivity of SiO₂ and Al₂O₃ and crystallinity of hydration products than that of coarser construction waste in hydrothermal reaction, after all, the high reactivity of SiO₂ and Al₂O₃ have a positive effect on the formation of tobermorite [11].

3.4. SEM analysis

The microstructure of AAC depends upon the characteristics such as type, amount and phase compositions of raw materials, conditions of hydrothermal treatment, and the type and distribution of hydration products formed in the AAC. From Fig 3. (A and B), it can be seen that the interior of the AAC has a pore structure, the existence of these pores greatly reduces the density of the product, and many hydration products are generated around the pores, combining with XRD (Fig 2.), it can be inferred these hydrated products are CSH gel and tobermorite, they tightly combine together to provide mechanical strength of AAC. As shown in Fig 3. (C and D), tobermorite, calcite and gelatinous CSH are exist, the tobermorite produced after autoclaving are mostly in the form of flakes [15], and the flaky tobermorite and columnar calcite are staggered together to form a certain porous and framework hierarchy, and gelatinous CSH embed in pores. This structure not only improve the strength of the AAC, but also reduce the density of the sample.

4. Conclusions

In this study, utilizing construction waste as the main raw material, cement, quicklime, gypsum and aluminum powder were added to prepare AAC, the following conclusions can be drawn:

(1) It is applicable to prepare AAC with construction waste. The recommended technological parameters are 55-65 wt. % construction waste, together with 15-21 wt. % cement, 18-22 wt. % quicklime, 2 wt. % gypsum and 0.1 wt. % aluminum powder, the construction waste is mechanical milled for 20 min, and the autoclave pressure is 1.5 MPa for 6 h, under these conditions, the dry density and compressive strength of AAC samples are 5.12 MPa and 696 kg/m³, respectively, which meet the requirements of A5.0 B07 grade in the Autoclaved aerated concrete blocks (GB11968-2006).

(2) XRD and SEM analysis shows that the flaky tobermorite and columnar calcite are staggered together to form a certain porous and framework hierarchy, and gelatinous CSH embed in pores, which contribute to the good properties of low density and high strength.

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