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Utilization of iron tailings as substitute in autoclaved aerated concrete: physico-mechanical and microstructure of hydration products

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ABSTRACT

Based on the background that a large amount of iron tailings was stockpiled in China, the most appropriate preparation conditions of producing autoclaved aerated concrete (AAC) with iron tailing was studied. The slurry properties were tested to evaluate the effects of the raw material factors on gas forming character. The compressive and specific strengths were measured to assess the feasibility of producing B05, A2.5 AAC blocks. The analysis of morphology, mineral components and thermal property were carried out in order to determine the mineral composition of iron tailing AAC blocks. Leaching toxicity was determined to ensure the environmental safety of iron tailing AAC blocks. The results shows that under the following conditions, cement 8%, quicklime 21%–27%, 20 min ball milled siliceous 62%–68% (with 40%–60% substituted by iron tailings), gypsum 3%, ratio of water to raw material (W/R) 0.6, aluminum (Al) powder 0.14% and at 1.4 MPa steam pressure maintaining for 8 h, the bulk density can be between 490 and 525 kg/m^3, compressive strength higher than 2.5 MPa and specific strength higher than 4700 N m/kg. The main minerals in the AAC were dough-like CSH gel, flake-like tobermorite and long-strip anhydrate besides quartz and other residual minerals from the iron tailings. The compressive strength is mainly attributed to the interconnected microstructure constituted of CSH gel and tobermorite. The thermal analysis also proved the existing of the main minerals.

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1. Introduction

Autoclaved aerated concrete (AAC) is a lightweight and highly porous material with excellent thermal insulation ability which can be used both in load bearing wall and filler wall (Narayanan and Ramamurthy, 2000; Karakurt et al., 2010; Jerman et al., 2013). The physical and mechanical properties of AAC are mainly determined by the hole-wall composition of hydration products and the pore size distribution (Alexanderson, 1979; Abbate, 2004).

The promotion of Chinese government on building energy saving and carbon emission gives autoclaved aerated concrete a broad application prospect. The commercialized AAC is usually produced with cement and lime as calcareous materials, with quartz sand or fly ash as siliceous materials, and small quantities of aluminum powder as gas forming material. Recent trends in AAC have heightened the need for industrial wastes utilization in AAC production. Several researchers have investigated the possibility of replacing the traditional raw materials of AAC by industrial waste, such as fly ash (Andre et al., 1999), air-cooled slag (Mostafa, 2005), coal bottom ash (Kurama et al., 2009), efflorescence sand (Mirza and Al-Noury, 1986), copper tailings (Huang et al., 2012) and carbide slag (Fan et al., 2014), etc.

Iron tailings in China have been nearly totally piled up through the history of iron ore mining. As a by-product of iron ore, the iron tailings production ratio is 1:2.5–3.0 iron ore. By 2013, the total cumulative stockpiling of iron tailings in China was 5 billion tons and the number is keeping increasing as the rising of iron tailing emission, posing a severe threat to the environmental condition (Zhang et al., 2006).

Nowadays, the allowable disposal method for iron tailings is outdoor stack after solidify with curing agent, which may cause soil contamination, river and underground water pollution and

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Abbreviations: AAC, autoclaved aerated concrete; W/R, ratio of water to raw material; Al, aluminum; CaO, calcium oxide; P.O. 42.5, ordinary portland cement 42.5; MSIS, mass substitution ratio of iron tailing to silicon sand; FESEM, field-emission high resolution transmission electron microscopy; EDX, Energy Dispersive X-ray; XRD, X-ray diffraction; TG, thermogravimetric; DSC, differential scanning calorimetry; ICP-AES, inductively coupled plasma atomic emission spectrometry; CSH, calcium silicate hydrate; CASH, calcium aluminum silicate hydrate; DM, dry mixture; HAC, hardened aerated concrete; AFt, ettringite.

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potential danger (Dudka and Adriano, 1997; Licsk et al., 1999; Moreno and Neretnieks, 2006). Thus, for environmental protection and sustainable development, utilization of iron tailings has become an issue. Many studies engaged in utilizing iron tailings such as recovery (Sirkeci et al., 2006; Das et al., 2002), fired blocks (Yang et al., 2014), ceramsite (Das et al., 2000), concrete aggregate (Zhao et al., 2014), and additives in the ceramic industry (da Silvaa et al., 2014).

Producing building materials is a mature technical route for utilizing waste, and a great number of methods in this field have been reported. Most of the studies reported the utilization of waste on autoclaved brick with good quality (Ahmari and Zhang, 2012; Kumar and Kumar, 2013; Zhang, 2013; Zhao et al., 2009; Du et al., 2014). Some of them have studied the leaching behavior to ensure the service safety of the material (Tanrıverdi, 2006; Ahmari and Zhang, 2013). As for AAC, most scholars focused on the preparation of B06 AAC blocks which were classified in the national standard GB/T 11968-2006, but few studies involved B05 or much lighter AAC blocks. Meanwhile, most of the studies were reported on the macro-property and micro-structure of AAC blocks, but they neglected the influence of slurry properties and gas forming process.

The objective of this study is to investigate the feasibility of producing B05, A2.5 AAC blocks with iron tailings. The SiO_2 in iron tailings used to replace quartz sand as silicon material. In addition, calcium oxide (CaO) in iron tailings was considered as partly alternative calcareous resource to reduce the consumption of lime. This paper mainly discussed the influence of quick-lime content, iron tailing content and siliceous fineness on the slurry gas forming character and AAC mechanical property, meanwhile, the influence of steam pressure maintaining time on AAC mechanical property is also discussed. Additionally, to make primary understanding of reaction mechanism during the process of dry mixing, pre-curing and autoclaving, the micro-structural and phase compositions of the AAC blocks prepared by iron tailings were investigated. Leaching toxicity was measured to examine the environmental safety of iron tailing AAC blocks.

2. Material and methods

2.1. Raw materials

Raw materials contained silicon sand, iron tailing, cement, quicklime and calcium sulfate dihydrate (analytically pure). All the raw materials used were from the same batch to ensure the stability of the chemical compositions. The chemical components of raw materials were shown in Table 1.

Iron tailing discharged by ore-dressing machinery was sampled from the Wuhan Iron and Steel (Group) Company in China. Cement and quicklime were used as calcareous materials to provide CaO in the autoclaved hydrothermal reactions. Quicklime had 71.6% active CaO and its residue on 80 μm sieve was 9.3% with 12 min digestion time, 87 °C digestion temperature. The cement was commercial ordinary portland cement 42.5 (P.O. 42.5) provided by Hubei Yadong cement Co., Ltd. The calcium sulfate dihydrate (analytically pure) was made by Sinopharm Chemical Reagent Co., Ltd. Al powder was used as a gas producing agent for the slurry foaming, which had 80%solid content, 86%active Al content, and its coating surface on water was 5417 cm^2/g.

2.2. Procedure

The mixture proportion and K_{alk} (Du et al., 2014) of each sample were shown in Table 2. The percentage content of cement, gypsum, Al powder and water were constant. Sample T1-T5 was set to investigate the effect of different quicklime contents on the properties of slurry and AAC blocks. The quicklime content varied between 19% and 27%, meanwhile, the siliceous content changed from 70% to 62%, and the mass substitution ratio of iron tailing to silicon sand (MSIS) was constant at 40%. The samples T2, T6-T11 were set to investigate the effect of MSIS on the properties of slurry and AAC blocks by maintaining the dosage of quicklime at 21% and varying MSIS with 0%, 20%, 40%, 50%, 60%, 80% and 100%. The effect of the siliceous fineness on the properties of slurry and AAC blocks was investigated by maintaining the dosage of quick lime at 21% and MSIS at 40% with the samples T2, T12-T15.

The flow chart of preparation of raw materials and samples was shown in Fig 1. Raw materials in each sample were weighed according to the mixture proportions in Table 2. The margins of weight errors of powder materials and water were controlled in ±0.2 g, and that of Al powder was controlled in ±0.02 g. The powder materials were thoroughly dry mixed before adding warm water (50 ± 1 °C) and then stirred for 2 min. After that, Al powder was added and mixed with the slurry for another 45 s. The ultimate slurry was poured into $100 \times 100 \times 100\ mm^3$ moulds, and it pre-cured at the temperature of 50 ± 2 °C under a steam saturated condition for 2.5 h. After that, cutting the swollen up surface to flat, and demoulded to getting the green body. Finally, the green body was put into an industrial autoclave for hydrothermal reaction. The pressure in the autoclave was kept at 14 bars for 8 h before obtaining the final products.

2.3. Analysis methods

The true density and specific surface area of raw materials were determined according to GB/T 208-2014 and GB/T 8074-2008, respectively. The particle distributions were detected by particle size analyzer, Marlvern Mastersizer 2000.

The gas-foaming rate were carried out by recording the slurry volume value in a 250 ml measuring cylinder with 100 ml initial slurry every 2 min until the slurry stopped expanding. The compressive strength was tested according to GB/T 11969-2008. In order to compare the compressive strengths of the samples with different bulk densities, a formula of specific strength(S) was defined as $S = \sigma(MPa)/D\ (kg/m^3)$ (σ:tested compressive strength of the AAC samples; D: bulk density of the AAC samples). Nine samples were carried out in each performance test.

The chemical components of the raw materials were determined by X-ray fluorescence spectrometer. The crystal structure of the iron tailing and AAC samples were detected by a D/8 Adwance X-ray diffractometer with Cu Kα radiation from 5° to 70°. The microtopography of iron tailing and AAC samples was characterized by using JSM-5610LV scanning electron microscope and JEM-2100F field-emission high resolution transmission electron microscopy

Table 1
Chemical composition of the raw materials (%).

Component	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	SO_3	CO_3	Cl	Ignition loss (%)
Silicon sand	90.21	4.51	1.24	0.40	0.10	0.27	2.54	0.03	–	0.03	0.47
Iron tailing	42.90	10.75	7.51	12.97	7.10	2.06	1.96	9.04	–	0.10	4.48
Cement	17.76	3.94	4.04	61.11	1.78	–	0.29	3.52	6.32	–	0.73
Quicklime	2.78	1.02	0.73	73.64	1.45	–	0.13	0.33	12.7	0.01	6.94

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