Materials and Design 97 (2016) 155–162

Contents lists available at ScienceDirect

Materials and Design

journal homepage: www.elsevier.com/locate/matdes

Fabrication and characterization of self-ignition coal gangue autoclaved aerated concrete

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ARTICLE INFO

Article history:
Received 30 August 2015
Received in revised form 15 February 2016
Accepted 17 February 2016
Available online 21 February 2016

Keywords:
Self-ignition coal gangue
Autoclaved aerated concrete
Orthogonal experiment
Tobermorite

ABSTRACT

By conducting the orthogonal design for the best mechanical properties of the matrix parts without introducing air pores in advance, the self-ignition coal gangue: lime: cement: gypsum = 54: 23: 20: 3 accompany with 1.3‰ aluminum powder is determined as the optimal mix proportion of the self-ignition coal gangue aerated concrete. Meanwhile, the reasonable Ca/Si ratio of the elements is found to be 0.82. XRD results show that the hydration products of self-ignition coal gangue autoclaved aerated concrete (SCGAAC) are mainly consisted by CSH gel and tobermorite phase, moreover, SEM approved that a higher Ca/Si ratio is conducive to form the tobermorite phase under the autoclaved conditions. The induced pores in SCGAAC are mainly interconnected open cell structure with middle characteristic latitudinal dimension between 0.5 and 2 mm.

1. Introduction

Coal gangue (CG) accounting for approximately 10% of coal production is the commercial worthless rock that surrounds, or is closely mixed with coal. Coal mining which contain some inorganic minerals and organic matter results in substantial ecological and environmental problems, including cropland occupation, pollution of groundwater resources, soil pollution, etc. [1–3]. The main inorganic components of coal gangue contain silicon, aluminum, calcium, magnesium, iron oxide and some rare metals. The pyrite (FeS_2) components in coal gangue tend to be oxidized easily and release heat spontaneously. As the heat accumulation, the temperature in coal gangue hills increased gradually. Spontaneous combustion would be caused when the ignition point arrived. The harmful gas produced by coal gangue spontaneous combustion (such as CO, SO_2, NO_x, etc.) posed the serious threat to the safety of the mining areas. In the 21st century, the use of CG has been considered from an environmental point of view. For example, in 2002, about 130 million tons of gangue was produced per year from coal mining in China. This, mixed with the 60 million tons of coal mud also produced, could be used for power generation; and the coal mining gangue could be combined with coal ash or other solid waste to produce building materials [4]. The stock pilings of coal gangue have become an urgent problem to solve.

CG was usually used as aggregate in fill back projects due to its low pozzolanic activity compared to the normal supplementary cementitious materials such as fly ash and slag [5]. The active SiO_2 and Al_2O_3 components in the coal gangue have the potential of secondary hydration reaction and then improve the microstructure and mechanical properties [6]. The main components of CG, which are mainly crystalline state SiO_2, have low pozzolanic activity especially at room temperature [7]. To obtain a better mechanical performance, CG blended cement is studied which contains 52% CG activated by a mechanical-hydro-thermal method [8]. Compared with the traditional clinker producing process, energy consumption for producing activated CG could save 90.7 kg/ton equivalently [7]. Furthermore, activated CG is presented as one mainly raw material to produce the cementitious material with red mud [9]. A glass ceramics is prepared using up to 70% CG as the main starting materials that exhibits attractive physical, mechanical and corrosion resistance properties, showing large application potential for construction purposes [5].

Since autoclaved aerated concrete (AAC) can be produced using a wide range of cementitous materials that containing enough silicon contents, i.e. fly ash or quartz sand powder, which could react with calcium hydroxide to form calcium hydrate at autoclaved conditions. In order to make full use of industrial waste, there is a development trend around the world for AAC industry to use industrial waste as mainly raw materials. Mostafa et al. replace partial lime and sand in AAC with air-cooled slag [10]. The concrete having 25% and 50% coal bottom ash usage has also beneficial effect on the strength gaining of the AAC, and thermal conductivity values reduces with increasing coal bottom ash replacement ratio [11]. The AAC specimens are prepared with copper tailings on a laboratory scale with a dry density of 610.2 kg/m^3 and compressive strength of 4.0 MPa [12]. Kunchariyakun

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http://dx.doi.org/10.1016/j.matdes.2016.02.068
0264-1275/

examines the effects of rice husk ash on the physical, mechanical and microstructural properties of AAC, and the results demonstrated that rice husk ash substitution for sand reduces compressive strength and unit weight [13].

Self-ignition coal gangue (SCG) is one naturally activated CG which has used the heat generated from the spontaneous combustion process of CG. In this paper the chemical composition of self-ignition coal gangue is presented and its activity is analyzed. The paper also discloses a self-ignition coal gangue autoclaved aerated concrete (SCGAAC) material and a production method thereof, wherein the material takes the SCG as a main material.

2. Materials and experimental methods

2.1. Raw materials

In this study, the coal gangue (CG) raw materials (Fig. 1) were obtained from Dalianhe, China. The matrix materials of SCGAAC are produced from SCG, ordinary Portland cement (PC), lime (L) and gypsum (G). The chemical analysis results of the raw materials are listed in Table 1. The reference specimen was fly ash autoclaved aerated concrete (FAAAC), and the chemical analysis of fly ash (FA) was shown in Table 1. The gangue which size ranged from 10 mm to 30 mm was similar to the coarse aggregate. The sieve residue of SCG through 80 μm sieve is <9.2% after grounded in the SMΦ500 × 500 type ball mill for 1 h. Naphthalene-based superplasticizer (FDN) is selected for adjusting the slurry expansion (SE) of all pastes. Aluminum powder (AP) is used as forming agent when preparing the entire SCGAAC with introduced pore.

2.2. Specimens of SCGAAC matrix

Optimal mechanic performance of SCGAAC matrix blocks is the premise for the compressive strength of SCGAAC. Using the SCG, ordinary Portland cement (PC), lime (L) and gypsum (G) as matrix material of AAC, an orthogonal experiment with different match rations of AAC is conducted in Table 2. The desirable mix ratio is elected by the average compressive strength (σ) of every six measured specimens sized in 70.7 mm × 70.7 mm × 70.7 mm. Water to solid (W/S) ratio is fixed as 0.5. The appropriate temperature and pressure for preparing the coal gangue autoclaved aerated concrete is scheduled as 1.1 MPa and 187 °C, respectively. The amount of raw materials prepared was determined by the calcium to silicon (Ca/Si) ratio and the mold size. The Ca/Si ratio range of matrix specimens studied in the paper is similar to that of common AAC [14].

Fig. 1. Self-ignition coal gangue from Dalianhe mining area.

Table 1
Chemical composition and loss on ignition of raw material.

Oxide (wt %)	CG	FA	PC	L	G
CaO	1.18	6.90	62.31	85.33	29.93
SiO_2	61.02	58.49	21.05	3.28	7.31
Al_2O_3	23.55	21.80	5.50	–	11.70
Fe_2O_3	6.70	8.43	3.92	–	0.60
MgO	0.52	1.30	1.72	5.20	0.18
SO_3	–	0.16	2.66	–	38.84
Loss on ignition	2.5	0.29	–	–	9.62

2.3. Specimens of SCGAAC

CG, lime and aluminum powder have been chosen as three mainly factors here. The designed method with aluminum powder added groups have been listed in Table 3. The dosage of aluminum powder adopts three levels as 1.3‰, 1.5‰, and 1.7‰ to the matrix materials.

It should be noted that SE is one of the most important factors for AAC preparation. Confirming a similar SE for all test specimens can eliminate the interference arising from different flow behavior. SE is controlled in the scope of 290 ± 10 mm by adjusting the FDN proportion. The instrument used for the SE measurement is a hollow steel cylinder with 5 cm inner diameter and 13 cm height (Fig. 2a). Firstly the cylinder is vertically positioned on a piece of wetted glass panel (45 cm × 45 cm), after that prepared slurry should be poured into the cylinder totally. The cylinder needs to be lifted up to 15 cm vertically and a circular slurry disk will be formed on the glass instantly. The average max diameter in two vertical directions is taken as the SE (Fig. 2b). W/S ratio is adopted as 0.45 for all of the 9 groups tested in this part.

An optimum mixture of FAAAC was determined as FA: L: PC: C = 69:15:12:4 with 0.53 W/S ratio and 1.5‰ aluminum powder through amount of experiments. As the reference specimens, the same fabrication process and curing condition as SCGAAC were adopted.

2.4. Microstructure and property

Three techniques are taken to parse microstructure of SCGAAC, such as XRD, SEM and Super depth of field microscope (SDFM).

XRD analysis was performed to investigate the phase changes in the SCGAAC specimens during the autoclaving process. Followed XRD analysis, SEM analysis provided microstructural aspects of various specimens. Both methods were exerted to observe the microstructure of SCGAAC.

Mercury intrusion porosimetry (MIP) method is the common method to evaluate the properties of the pores of the ordinary concrete, but failed to evaluate the AAC pores with relatively bigger radius and lower strength. To characterize the geometric parameters of the formed pores in AAC, SDFM is adopted. Well-cured SCGAAC cubic blocks (70 mm × 70 mm × 70 mm) are cut into three slices (one inner slice

Table 2
Orthogonal experiments design for the matrix compositions of CGAAC.

	No.	Orthonormal sets	A. CG (g)	B. PC (g)	C. L (g)	D. G (g)	σ (MPa)
Scheme	m-1	A1B1C3D2	900	140	280	56	15.65
	m-2	A2B1C1D3	950	140	140	70	6.25
	m-3	A3B1C2D3	1000	140	210	42	9.90
	m-4	A1B2C2D3	900	210	210	70	11.44
	m-5	A2B2C3D1	950	210	280	42	17.53
	m-6	A3B2C1D2	1000	210	140	56	8.95
	m-7	A1B3C1D1	900	280	140	42	12.63
	m-8	A2B3C2D2	950	280	210	56	13.65
	m-9	A3B3C3D3	1000	280	280	70	18.70