Cement and Concrete Composites 72 (2016) 146–154

Contents lists available at ScienceDirect

Cement and Concrete Composites

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

Enhancement mechanism of new type autoclaved calcium carbide residue shell-aggregate on concrete

Hailong Ma [a, *], Chong Cui [b], Wentao Ma [c], Youzhen Yang [d], Guoqiang Tang [b]

[a] Institute of Ethnic Preparatory Education, Ningxia University, Yinchuan 750021, China
[b] School of Materials Science and Engineering, Nanjing University of Science and Technology, Nanjing 210094, China
[c] School of Mathematics and Computer Science, Ningxia University, Yinchuan 750021, China
[d] School of Physics and Electrical Information Science, Ningxia University, Yinchuan 750021, China

ARTICLE INFO

Article history:
Received 11 December 2015
Received in revised form
20 May 2016
Accepted 31 May 2016
Available online 4 June 2016

Keywords:
Mechanical properties
Concrete
Reinforcement
Aggregate
Curing

ABSTRACT

Enhancement mechanism of new type autoclaved shell-aggregate on concrete was studied by the experiment, using the X-ray diffraction, scanning electron microscopy, and the homogenization analysis methods. The experimental results indicate that effective elastic modulus of shell-aggregate match with the elastic modulus of the mortar matrix, which can explain the enhancement effect of shell-aggregate on mortar matrix. Homogenization method can reflect the actual contribution degree of autoclaved aggregate on concrete performance ideally. Errors between the calculated value and the measured value are only 5%, 6.7%, and 5.8% when the volume fractions of aggregate are 16%, 32%, and 44%, respectively. High strength of autoclaved shell-aggregate concrete is due to a combined action of matched elastic modulus between autoclaved shell-aggregate and mortar matrix, active gradient interface structure between shell-aggregate and mortar matrix, and small deviatoric tensor of stress between shell-aggregate and mortar matrix.

1. Introduction

C_2H_2 produced by calcium carbide acetylene method is an important chemical material, which is used mainly to weld metal and make acetaldehyde, acetic acid etc. According to an estimate, the consumption of 1 ton of calcium carbide generates about 1.5 ton calcium carbide residue (CCR) as a by-product. CCR produced by calcium carbide acetylene method is expected to exceed 100 million tons each year in Ningxia province, China [1]. Most of this residue is directly disposed into the natural mountain where it gets piled up and pollutes the soil and underground water, so there is an urgent need of a comprehensive treatment of CCR.

The light-weight and high-strength aggregates are popular for use in high-rise and large-span structures because they offer improved physical properties, including reduced dead weight, higher insulating coefficients, and superior sound-damping qualities compared with normal-weight aggregates [2–5]. Therefore, many researchers are continuously investigating the production of the light-weight and high-strength aggregates from various types of mining residues. To date, the studies have been mainly concentrated on the production of the light-weight and high-strength aggregate by a sintering process [6–9], there are no reports available in open literature that utilize CCR to produce man-made high performance aggregate by the hydrothermal synthesis and autoclave curing process.

In this paper, firstly, calcium carbide residue shell-aggregate (CCRS-A) was prepared by the hydrothermal synthesis of CCR and silica materials in the condition of 180 °C saturated steam. Secondly, the effective elastic modulus and Poisson ratio of CCRS-A were studied by homogenization method. Thirdly, the effect of shell apparent appearance on the performance of concrete was investigated by experiment. Fourthly, the effect of aggregate shape on performance of concrete was also studied by experiment. At last, the high strength mechanism of shell-aggregate concrete was discussed deeply.

2. Material and methods

2.1. Materials

CCR employed in this experiment was collected from Ningxia

* Corresponding author.
E-mail address: mhl@nxu.edu.cn (H. Ma).

http://dx.doi.org/10.1016/j.cemconcomp.2016.05.027

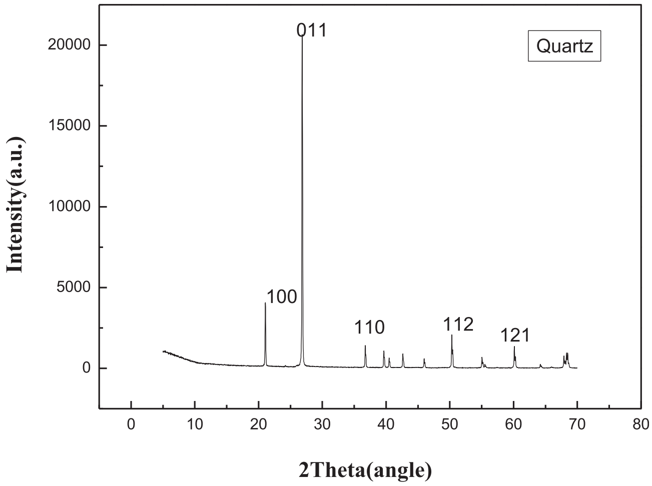

Fig. 1. XRD result of cobblestone.

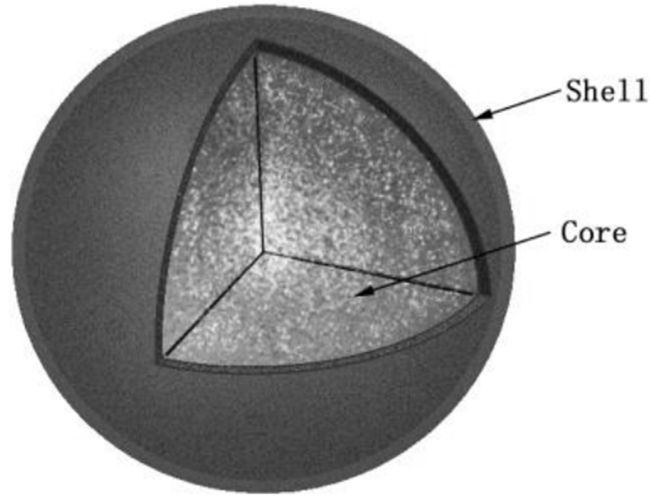

Fig. 2. Schematic diagram of CCRS-A.

Yinglite Chemicals Co., Ltd in China, in which moisture content was 40.8%. The particle size distribution of the CCR was analysed by laser diffraction in the range from 0.6 to 190 μm. The main mineral constituent of the CCR is calcium hydroxide {$Ca(OH)_2$}, followed by the calcium carbonate ($CaCO_3$). Fly ash (collected from Yinchuan thermal power station, China) having specific surface area of 378 m^2/kg and specific gravity of 2.15 was used. The main mineral constituents of fly ash were glass phase mullite and a-quartz. Powdery quartz sand used as fine aggregate was supplied by Zhong Peng Water Purifying Materials Limited Company, Shizuishan, China, which was broken tails of quartz sand used to produce glass. After sieving, the particle size of all powdery quartz sand was below 600 μm, the major mineral component of powdery quartz sand is a-quartz. Ordinary Portland cement was used for the production of both the CCRS-A and cement mortar. Polycarboxylic acid type water-reducer was used to obtain proper workability of both CCRS-A and cement mortar matrix, whose water reducing ratio is 30%. Hydrophobic paint came from Nanjing Yangtze River Coatings Co., LTD, whose main compositions are alkyd and pigment, rosin water was chosen for diluent, ratio between paint and rosin water was 1:0.8. Cobblestone collected from Zhong Peng Water Purifying Materials Limited Company, Shizuishan, China, whose XRD result is shown in Fig. 1, it can be seen from Fig. 1 that the major mineral component of cobblestone is quartz. The sintering shale aggregate (SA) was produced under the sintering temperature of 1150 °C by Nantong Dadi Aggregate Limited Company, China and the crushed stone (CS) was collected from some building site of Yinchuan. The chemical compositions of CCR, fly ash, powdery quartz sand and cement employed in the study are given in Table 1.

2.2. Preparation method

CCRS-A: In hydrothermal synthesis and autoclaved treatment, the type of phase that emerges mainly depends on the original Ca/Si ratio when autoclaved temperature and curing time of the hydrated calcium silicate system are kept fixed, and the types and numbers of phase determine the strength of products. When Ca/Si ratio is near 0.83, the main hydrated product of the hydrated calcium silicate system is high-strength tobermorite. On the other hand, previous results indicated that incorporation of powdery quartz sand and shell can improve the strength of autoclaved aggregate [10]. Therefore, powdery quartz sand, Ca/Si ratio, shell thickness (ratio of the mass of the shell to the mass of core) and shell constituent (ratio of the mass of fly ash to the mass of cement) have been chosen as the mix proportion factors, mix proportion of CCRS-A was shown in Table 2.

First, the powdery quartz sand, fly ash and CCR were mixed. Then the mixture was transferred to a self-made pelletization disc after stirring uniformly. At last, the rolling and forming of the aggregate was done. When the core had a spherical structure, the shell outside of the aggregate was formed. After 24 h of natural curing, the aggregates were placed into an autoclave, and after 3 h, the curing temperature was raised from room temperature ($T = 20$ °C) to 180 °C and to a pressure of $P = 145$ psi. The temperature was maintained constant at 180 °C for 8 h, and then cooled

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

Materials	SiO_2	Al_2O_3	Fe_2O_3	CaO	Water content	LOI	Activated-CaO
CCR	4.73	4.17	0.39	69.71	40.81	17.04	36
Fly ash	44.41	29.88	6.54	4.22	0.60	12.96	
Powdery quartz sand	67.84	13.71	2.62	2.78	0.42	0.00	
Cement	21.64	8.83	4.23	57.02	0.24	1.01	

Table 2
Mix proportion of CCRS-A.

Aggregate	Dosage of powdery quartz sand (%)	Ca/Si ratio	Shell thickness (%)	Shell constituents
CCRS-A	15	0.70	4	80:20