Construction and Building Materials 163 (2018) 949–959

Contents lists available at ScienceDirect

Construction and Building Materials

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

Effects of pore structure and water absorption on internal curing efficiency of porous aggregates

Dinghua Zou, Kun Li, Weidong Li, Haiyan Li *, Tianlu Cao

School of Materials Science and Engineering, Henan Polytechnic University, Jiaozuo, Henan 454000, PR China

HIGHLIGHTS

- Water release rate of aggregate is almost constant at invariant RH.
- Pore structure has intensity effect on equilibrium water in aggregate, but no impact on water release rate.
- Water release rate has linear relationship with reciprocal of volume water absorption.
- Water release rate reflects effect of surface area on efficiency of internal curing aggregate.
- In desorption test, denser container and piling of particles should be avoided.

ARTICLE INFO

Article history:
Received 8 June 2017
Received in revised form 25 October 2017
Accepted 25 December 2017

Keywords:
Internal curing
Aggregate
Water desorption
Cementitious materials
Pore structure
Relative humidity
Autogenous deformation

ABSTRACT

This paper presents the results of experimental investigation on desorption behavior and internal curing efficiency of porous aggregates with same size fraction from 2.36 to 4.75 mm, but different pore structure and water absorption. Water release rate and equilibrium remaining water of aggregates at different relative humidity were obtained in desorption test. Internal relative humidity, autogenous deformation, and compressive and flexural strength of plain and internally cured mortar were measured. Based on the analysis of results, it was revealed that, pore structure of the aggregate has intensity effect on equilibrium residual water, but indistinct on water release rate. The rate is linearly proportional to the reciprocal of volume water absorption of the aggregate. Pore structure and volume water absorption influence the internal curing efficiency of aggregates. Bigger pores and lower volume water absorption of aggregate facilitate the internal curing. Therefore, water release rate, as well as equilibrium remaining water, could be used to characterize the internal curing efficiency of aggregates.

1. Introduction

As the processing of the researches on internal curing, many kinds of porous aggregates were taking as the water reservoirs to provide the additional water for mitigating the self-desiccation and high shrinkage in low w/c concrete and mortar [1]. Expanded shale [2–7] and clay [8–12] are the most common ones. Slag [13], bottom ash [14], and pumice [15–17] were also used. However, the decrease of the compressive strength of internally cured concrete and mortar at early age were usually observed when they were employed [8,18–20]. Porous aggregates with higher densities than lightweight aggregate, for examples the waste ceramic aggregate [21] and normal weight porous aggregate (NWPA) [22], were developed to eliminate the descent of compressive strength. Improvement of compressive strengths of mortar accompanying them was observed.

Based on the idea that cement reaches the possible maximum degree of hydration, equation was derived to calculate the content of internal curing agent and proved to be effective [23]. What makes it complicate is that, the disparity of the properties of these aggregates results in the different desorption behavior and thus the volume deformation of internally cured concrete and mortar. The compare between natural pumice and artificial expanded clay and slate revealed that [8], former one has higher water absorption and faster water release speed than latter aggregates due to its higher open porosity and interconnectivity of pores. NWPA showed the lower internal curing efficiency than expanded clay but faster water absorbing [17]. Slag aggregates [13] obtained from different producing processes also showed the distinction on desorption behavior. The shrinkage of mortar accompanying low efficiency slag is contrary to the expansion of the counterpart. The

* Corresponding author.
E-mail addresses: zoudinghua@hpu.edu.cn (D. Zou), lihaiyan@hpu.edu.cn (H. Li).

https://doi.org/10.1016/j.conbuildmat.2017.12.170
0950-0618/

compressive strength is also lower due to the insufficient internal curing. Residual water was used as the index to evaluate the efficiency of internal curing agent. In ASTM C 1761/C1761M [24], it was suggested that the internal curing agent should lose more than 85% of the water it absorbed at the relative humidity (RH) of 94%.

To clarify the effect of properties of porous aggregate on its internal curing behavior, water desorption of 5 porous aggregates were surveyed. Mercury intrusion porosimetry (MIP) and scanning electron microscope (SEM) were used to reveal the diversity of pore structure of the aggregates. Residual water and water release rate were analyzed to reveal the impact of pore structure and water absorption on desorption behavior of aggregates. Internal relative humidity, autogenous deformation, and compressive and flexural strength of plain mortar and internally cured mortars were measured. This paper aims to provide a more comprehensive understand on influence of desorption behavior of porous aggregate on its internal curing efficiency.

2. Materials and methods

2.1. Aggregates for desorption test

Fig. 1 shows the aggregates. Five artificial aggregates, including 2 clays, NWPA, shale, and coal bottom ash were employed. Clay 1 was produced in Zhenjiang, Jiangsu Province, China. Clay 2 was obtained from the particles of crushed clay brick, which was fabricated in Jiaozuo, Henan Province, China. Shale was manufactured in Yichang, Hubei Province, China. Coal bottom ash was acquired from Xingyang power plant, which locates in Zhengzhou, Henan Province, China. To diminish the influence of gradation, particles with single size fraction from 2.36 to 4.75 mm were employed. Saturated surface dry (SSD) density and water absorption of the aggregates are shown in Table 1.

2.2. Materials and mixtures of mortars

A class 42.5 Portland cement, according with Chinese national standard GB 175-2007, was taken as binder. Chemical compositions and properties of cement are presented in Tables 2 and 3. Natural river sand was employed as normal fine aggregate. SSD density and 24 h water absorption of sand are 2.57 g/cm3 and 2.06%, respectively. Polycarboxylate Superplasticizer was employed as water reducer.

In mixture design, w/c and fine aggregate volume fraction of all mortars were fixed as 0.3 and 55%, respectively. Content of internal curing aggregates were calculated according to Bentz's method [23]. Mixtures of mortar are presented in Table 4. Bottom ash and shale did not used in mortar due to their low water absorption.

2.3. Experiments

2.3.1. Water desorption test

A setup, just as what shown in Fig. 2, was used in desorption test. In desorption test, eight salt solutions of K_2SO_4, KNO_3, $BaCl_2$ $2H_2O$, KCl, KBr, NaCl, KI, NaBr were used to maintain the RH in 8 boxes respectively. As described in ASTM E104 [25] and reference [9], equilibrium RH of saturated solution of these salts are 97%, 93%, 90%, 85%, 81%, 75%, 70%, and 59%, respectively. Nylon sieves were used to contain the samples. Before test, sieves were placed in the box to reach the constant weight. Appropriate amount of sample in SSD condition was placed on mesh to prevent the particles from piling. The samples at 97% and 93% RH were weighted every 4 h. And the rest were weighted every 1 h. An electric balance, accurate to 0.01 g, was used in test. Room temperature was 23 ± 1 °C.

2.3.2. Characterization of aggregate pore structure

Mercury intrusion porosimetry (MIP) of aggregate was carried out by an AutoPore IV 9500 porosimeter. A Carl Zeiss Merlin Compact scanning electron microscope was used to investigate the microstructure of aggregates.

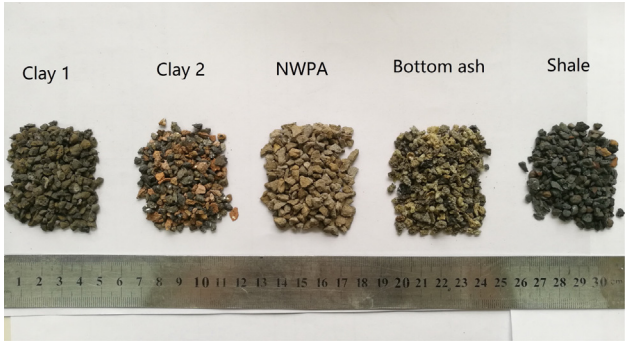

Fig. 1. Image of aggregates.

Table 1
SSD density and water absorption of aggregates.

No.	Clay 1	Clay 2	NWPA	Shale	Bottom ash
SSD density/g/cm^3	1.27	2.12	2.23	1.52	1.84
Mass water absorption at 24 h/%	30.8	14.7	23.6	4.8	4.7
Volume water absorption at 24 h/g/cm^3	0.299	0.272	0.425	0.07	0.083

Table 2
Chemical compositions of cement mass%.

CaO	SiO_2	Al_2O_3	SO_3	MgO	Fe_2O_3	K_2O	TiO_2	Loss in ignition (950 °C)
49.73	24.14	9.53	5.67	3.40	2.68	0.86	0.28	3.4

Table 3
Properties of cement.

Specific surface area (m^2/kg)	Initial setting time (min)	Final setting time (min)	Compressive strength (MPa)		Flexural strength (MPa)	
			3 d	28 d	3 d	28 d
391	143	203	30.2	49.5	6.2	9.4

Table 4
Mixtures of mortar kg/m^3

No.	Cement	Water	Sand (SSD)	Clay 1 (SSD)	Clay 2 (SSD)	NWPA (SSD)	Water reducer
Plain	728	218	1413	–	–	–	3.5
Clay 1	728	218	1078	165	–	–	3.5
Clay 2	728	218	1045	–	303	–	3.5
NWPA	728	218	1177	–	–	203	3.5