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Internal curing of mortar with low water to cementitious materials ratio using a normal weight porous aggregate

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HIGHLIGHTS

- A normal weight porous aggregate, with SSD density of 2.3 g/cm^3, was prepared.
- Normal weight porous aggregate absorb water faster than expanded clay.
- Normal weight porous aggregate increase the compressive strength of mortar.
- Normal weight porous aggregate could effectively diminish the shrinkage of mortar.
- Normal weight porous aggregate reduce the heterogeneity of mortar after vibration.

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ABSTRACT

A normal weight porous aggregate (NWPA), with the saturated surface dry density of 2.3 g/cm^3, was prepared. Impact of NWPA on performance of mortar with water to cementitious materials ratio of 0.3 was presented in this paper. The results show that NWPA has smaller pores and higher water absorption speed than expanded clay, but lower desorption speed. Strength of mortar accompanying NWPA is higher than or close to that of a plain one. Mortar containing NWPA expand less than that with expanded clay under sealed condition, which suggests the lower internal curing efficiency of NWPA. However, still it could diminish the shrinkage of low w/c mortar and be used as internal curing agent. Variation of water absorption and dynamic modulus from top to bottom of mortar with NWPA is similar to that of plain one, and lower than that of expanded clay mortar, which certifies that NWPA could promote the uniformity of internally cured mortar.

1. Introduction

Due to the low permeability of mortar or concrete with low water to cementitious materials ratio (w/c), internal curing is rather more efficient than an external one to diminish the high autogenous shrinkage of it [1–4]. Benefiting from the additional water introduced by internal curing agent, low w/c mortar and concrete under sealed condition usually expanded [5–8] when their mixtures was designed as Bentz's method [9].

The descend of strength of internally cured mortar or concrete at early age (7 days or earlier) usually was observed [10–14] due to the porosity of lightweight aggregate (LWA). However, this was the results under free condition. A plain mortar would be damaged due to the high stress induced by high autogenous shrinkage when it was restrained. For mortar internally cured by LWA, low shrinkage or expansion prevent it from the damage [12]. Decrease of strength would not come to be a problem of internally cured mortar or concrete. What would be the obstacle in application of internal curing is that, density difference between moist internal curing agent and paste is much higher than that between ordinary fine aggregate and paste. In a flowable concrete and mortar, or when they were vibrated or pumped, particles of internal curing agent would go up if the upward resultant of buoyancy and additional force induced by vibration or pumping it suffer surpass the downward force due to viscosity of paste. This leads to the heterogeneity of mortar or concrete. Considering the impact of internal curing on deformation of mortar and concrete, top layer of concrete or mortar may expands while the bottom shrinks. Additional stress induced thereby.

Crushed waste ceramic [15–17] was proved more suitable for internal curing than LWA [18–20] and SAP [21,22] based on its impact on properties of mortar. Strength of the mortar accompanying crushed waste ceramic was higher than that of a plain

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counterpart. Moreover, saturated surface dry (SSD) density of crushed waste ceramic was 2.48 g/cm^3, which is very close to that of ordinary fine aggregate. However, insufficient waste ceramic hinder the application of it as internal curing agent.

In this research, an artificial normal weight porous aggregate (NWPA) was prepared to explore the way to obtain an applicable internal curing agent which has the SSD density close to ordinary fine aggregate. Properties of NWPA and its impact on performance of mortar were presented in this paper. Water absorption and desorption of NWPA were experimentally investigated. Mechanical properties, autogenous deformation of plain mortar and internally cured mortars accompanying NWPA and expanded clay, were tested. Uniformity of the mortars was characterized to highlight the difference between NWPA and ordinary LWA.

2. Preparation of NWPA

To obtain the NWPA, a heavy raw material, red mud, with the apparent density of 2.93 g/cm^3, was selected. Knar clay, with the apparent density of 2.48 g/cm^3, was used to improve the plasticity of red mud. Table 1 shows the chemical compositions of them.

Red mud and Knar clay were dried at 105 °C for 24 h. After cooled to room temperature, they were milled separately by a ball mill for 30 min. Red mud, Knar clay, and water, with the mass ratio of 0.65:0.07:0.28, were added in a mud refining machine to get the mud. Mud was molded into the bodies with the dimensions of 4 cm × 4 cm × 2 cm. The bodies were dried in an oven at 105 °C for 2 h. Dried bodies were heated to 1100 °C in a furnace at the speed of 10 °C/min and hold at that temperature for 5 min. Then they were cooled to room temperature in furnace after the sintering. Bodies were crushed to get the NWPA.

The SSD density and 24 h water absorption of NWPA are 2.30 g/cm^3 and 23.6%, respectively. An expanded clay was taken as reference of NWPA. Fig. 1 shows the NWPA and referenced expanded clay. Fig. 2 presents the cumulative percentage passing of NWPA and expanded clay.

Fig. 1. NWPA and expanded clay. Note: Left one is NWPA; right is expanded clay.

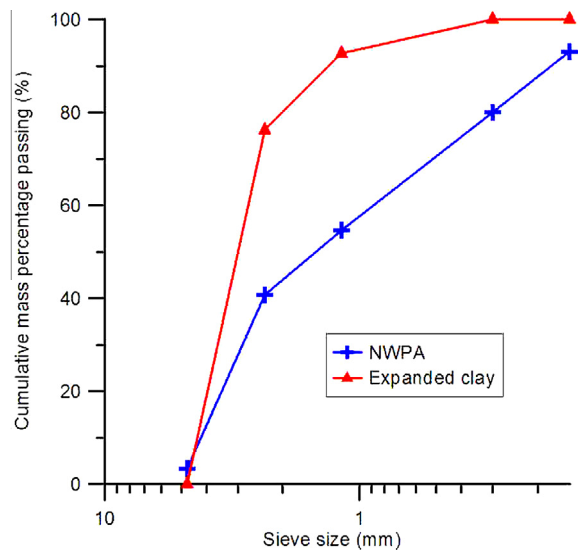

Fig. 2. Cumulative mass percentage passing of NWPA and expanded clay.

3. Materials and methods

3.1. Materials and mixtures

An ordinary Portland cement was used. Chemical, Mineral compositions and properties of cement are presented in Tables 1 and 2, respectively. River sand with the dry apparent density of 2.52 g/cm^3, 24 h water absorption of 2%, and fineness of 2.41 was employed. The SSD density and 24 h water absorption of expanded clay are 1.61 g/cm^3 and 38.7%, respectively. A high range polycarboxylate water reducer was employed also.

Water to cement ratio of mortars was 0.3. Volume fraction of fine aggregate was fixed as 55%. For internally cured mortar, mass content of internal curing agent was decided as Ref. [9]. Mixtures are presented in Table 3.

3.2. Experiments

3.2.1. Absorption and desorption of aggregates

An electric balance, accurate to 0.01 g, was used in absorption and desorption test. Room temperature was 20 ± 2 °C.

In absorption test, about 15 g aggregate was used. To avoid the loss of aggregate in wiping, particles with size fraction of 2.36–4.75 mm was used. At the age of 5, 10, 20, 30 min and 1, 2, 4, 8, 12, 24 h, sample was fished out and wiped to SSD condition to weight. Time of the operation was deducted from the ages.

Five specimens for each kind of aggregate in SSD condition was weighted for desorption test. Mass of each specimen was about 15 g. Specimens were placed in 5 plastic boxes respectively. Saturated salt solutions of K_2SO_4, KCl, NaCl, KI, NaBr were used to maintain the relative humidity (RH) in 5 boxes respectively. Fig. 3 shows the desorption test. As described in ASTM E104 [23], equilibrium RH of saturated solution of K_2SO_4, KCl, NaCl, KI, NaBr at 20 °C are 97.6 ± 0.6%, 85.1 ± 0.3%, 75.5 ± 0.2%, 69.9 ± 0.3%, 59.1 ± 0.5%. At first day, samples were taken out and weighted every 2 h. The interval of weight increased to 4 h at the age form 2 to 5 days and 24 h of the rest age.

Apparent density of grinding powder of NWPA and expanded clay were test according to ASTM C 1761/C1761M-12 [24] to calculate the porosity. Porosity of NWPA and expanded clay was calculated from Eq. (1):

$$p = 1 - \frac{\rho_i}{\rho_P} \qquad (1)$$

where p is porosity of internal curing agent; ρ_i is dry density of internal curing agent; ρ_P is dry density of powder of internal curing agent.

Water absorption of NWPA and expanded clay in vacuum was tested. Mercury intrusion porosimetry (MIP) of NWPA also was carried out.

3.2.2. Mechanical properties of mortars

Compressive, flexural and splitting tensile strength of mortars were tested according to Chinese standard GB/T 17671-1999 [25] and GB/T 50081-2002 [26]. Sample sizes for compressive, flexural and splitting tensile strength test were

Table 1
Chemical compositions of raw materials of NWPA and cement mass%.

	SiO_2	CaO	Al_2O_3	MgO	Fe_2O_3	SO_3	K_2O	Na_2O	TiO_2	Loss in ignition (950 °C)
Red mud	20.0	39.5	6.1	0.5	14.4	1.7	0.8	–	3.82	11.3
Knar clay	40.5	4.4	23.4	–	4.6	0.8	2.6	1.2	1.7	19.1
Cement	21.9	52.7	7.8	0.9	3.3	7.1	0.8	–	0.4	3.7