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Experimental investigation on shrinkage and water desorption of the paste in high performance concrete

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HIGHLIGHTS

- The shrinkage behavior of the paste in high performance concrete is studied.
- Two regression lines were established in each shrinkage vs water desorption plots.
- The cement-fly ash paste has highest shrinkage among the composite pastes.
- Increasing curing time and reducing w/c ratio reduces the shrinkage of cement paste.

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ABSTRACT

The shrinkage and water desorption of the cement paste with various mineral admixtures, water/binder (w/b) ratios and curing times were measured in different environmental humidity, and the shrinkage behavior of those pastes were analyzed by studying their pore structure. The results indicated that, the paste contains fly ash has highest shrinkage and rapidest water desorption among the pastes of cement, silica fume cement and ground granulated blast slag (GGBS) cement; the shrinkage increases with the w/b ratio and reduces with the curing time. The porosity and pore diameter in the early age paste control the water loss and water desorption rate and the shrinkage of the paste. The curves of shrinkage versus water desorption of different pastes were very similar, two regression straight lines were established in each plots, one was in relative humidity (RH) of 45% and 60%, the other one was in RH 15%.

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1. Introduction

High performance concretes (HPC) are often more susceptible to early age cracking than the concretes that were placed 50 years ago [1]. The reasons include the typically higher cement contents, the use of finer cements with higher tricalcium silicate and alkali contents, the formation of the denser paste matrix via the water reducer and the use of fine pozzolans e.g. silica fume, fly ash and GGBS [1,2]. The shrinkage of concrete is mainly caused by the shrinkage of the cementitious paste in it [1], and 60%–70% volume of the harden cementitious paste is occupied by calcium silicate hydrate (C-S-H) gel. C-S-H gel plays a decisive role on the shrinkage property [3,4]. With lower water/binder (w/b) ratio and mostly fine supplementary cementitious materials [5,6], the HPC has different microstructure and pore structure from the ordinary concrete. The C-S-H in HPC are some ultra high density (UHD) C-S-H [7,8], the shrinkage of the paste in HPC behaves much different from normal concrete. Shrinkage of HPC and Ultra High Performance Concrete (UHPC) has been intensively studied [9–11], it is influenced by w/b ratio, curing temperature, aggregate, various mineral admixture and chemical admixtures [12–22]. Some analytical and numerical modeling have been proposed [23–26] and simulation study [27] are carried out to determine the shrinkage or cracking of the concrete. But the shrinkage of paste of HPC in different relative humidity and the relationship between the water desorption and shrinkage need to be studied to clarify the mechanism of its shrinkage behavior.

The shrinkage driving forces mainly include capillary force, disjoint force and surface energy. When the relative humidity is more than 45%, the capillary force and the disjoint force will lead to large volume shrinkage of cement paste. If the relative humidity is less than 15%, the meniscus is unstable and the drying shrinkage is

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under the control of gel particle surface energy [28]. The shrinkage of the HPC paste measured as drying shrinkage is actually a holistic shrinkage of the chemical, autogenous shrinkage and drying shrinkage. Shrinkage is a balance between the volume reduction and the building up of the capillary network [29,30], even more the microstructure of the hardening paste. The driving force of this shrinkage is under the control of the capillary and surface energy induced by desiccation and self-desiccation in the cement paste. So shrinkage of the cementitous paste is controlled by the hydration process, pore structure, the water desorption rate of the cement paste. In this paper, the typical HPC paste is prepared with cement, supplementary cementitious material, high performance water reducer and low water/binder ratio. The shrinkage, water desorption and pore structure of those paste samples were measured, the influence of supplementary cementitious material, w/b ratio and curing time on the shrinkage and water desorption in different environmental humility was discussed, the difference of the pore structure was used to interpret shrinkage behavior the paste.

2. Experimental

2.1. Materials

The chemical compositions of cement, fly ash, GGBS and silica fume used in this paper are shown in Table 1, which are all commercially available. The water reducer is commercial polycarboxylate superplasticizer JM-PCA(Ⅳ), and the water is tap water of Wuhan City.

2.2. Experimental protocols

To figure out the influence of supplementary cementitious materials on shrinkage, proportions are design as Table 2. Dosage of water reducer and the w/b ratio are set as 0.6% and 0.23, respectively, according to the typical dosage of cementitious materials in the real HPC. As Table 3 shows, cement pastes are prepared with appropriate flowability in the study of influence of w/b ratio on the shrinkage. And the cement pastes, curing in humility ranging 99–100% for 1, 3 or 7 days before desaturation, are used to study the influence of curing time on shrinkage.

2.3. Experimental procedure and methods

The measurement of drying shrinkage was carried out following the Chinese standard Test Method for Drying Shrinkage of Cement Paste of JC/T603-2004, the dimension of prism specimens for drying shrinkage of measuring is 25 mm × 25 mm × 280 mm, three prism specimens were cast for each testing points. First of all, the cementitious paste specimens were casted and cured with the mould in the chamber with relative humidity of 99–100% for 24 h. Then the specimens were demoulded and brushed to remove the crumbs off it's surface, the weight and the length of each specimens were measured as the start points. Then specimens were put in box with relative humidity of 60 ± 1%, the length and the weight of the specimens were measured sequently at spans of time. When the shrinkage and weight loss (water desorption) became stationary, the specimens were put in the box with 45 ± 1% relative humidity. After that, when the weight loss is stationary again, the specimens were put in the box with15 ± 1% relative humidity, the weight and shrinkage of the specimens were tested until the shrinkage and weight loss become stationary. All the specimens were cured and measured at room temperature (20 ± 2 °C).

In the study of the influence of curing time on shrinkage of specimen, the curing time in chamber with 99–100% relative humidity were set as 1 day, 3 days and 7 days respectively before curing in the 60 ± 1% relative humility.

Table 1
The chemical compositions of cementitious materials (wt%).

Oxide (%)	Cement	Fly ash	slag	Silica fume
Al_2O_3	4.67	34.78	16.97	0.27
CaO	62.60	2.80	34.64	0.54
MgO	3.08	0.59	6.90	0.91
SiO_2	21.35	50.95	34.86	94.48
TiO_2	–	1.64	0.97	–
SO_3	2.25	0.67	1.65	–
Fe_2O_3	3.31	4.13	1.12	0.87
R_2O%	0.75	1.93	–	0.91
Others	1.99	2.15	2.89	0.99

Table 2
The proportions of cement cementitious pastes (wt%).

No	Proportion			
	C	FA	GBS	SF
S1	100	0	0	0
S2	70	30	0	0
S3	50	0	50	0
S4	90	0	0	10

Table 3
Water/binder ratio and the dosage of water reducer.

No	Cement (%)	w/b	Water reducer (%)
R1	100	0.45	0
R2	100	0.31	0.3
R3	100	0.23	0.6
R4	100	0.19	1.0

Samples for porosity measurement were collected in the middle part of the 28 day 50 mm × 50 mm × 50 mm cubic sample cured at temperature of 20 ± 2 °C with 95–100% relative humidity, then those samples were broken into particles no larger than 2 mm and dried in a vacuum desiccator. The pore structures of the binders were studied with PoreMaster 33–6 mercury porosimeter.

3. Results and discussion

3.1. The influence of mineral admixtures on shrinkage of cement paste

Shrinkages of pastes (w/b ratio = 0.23) with different mineral admixtures are provided in Fig.1. Results show that in the first nine weeks under the relative humidity of 60% and 45%, the shrinkage of pastes mixed with fly ash and silica fume is 30.12% and 24.22%, respectively, higher than that of control group i.e. cement paste. At the same condition, the shrinkage of paste mixed with GGBS is 6.92% higher than the control group [9]. At the relative humidity of 15%, the shrinkage of GGBS paste cement is a little lower than control group, and the fly ash paste cement is slightly higher than silica fume cement but much higher than control group. It is noteworthy that the shrinkages of those specimens measured in this work include the dry shrinkage and autogenous shrinkage, due to the low w/b ratio, the autogenous shrinkage prevails in the total shrinkage [28,29]. Ordinary, the fly ash concrete has lower shrinkage than concrete prepared with pure ordinary Portland cement [31,32], whereas, the shrinkage of fly ash cement paste has much

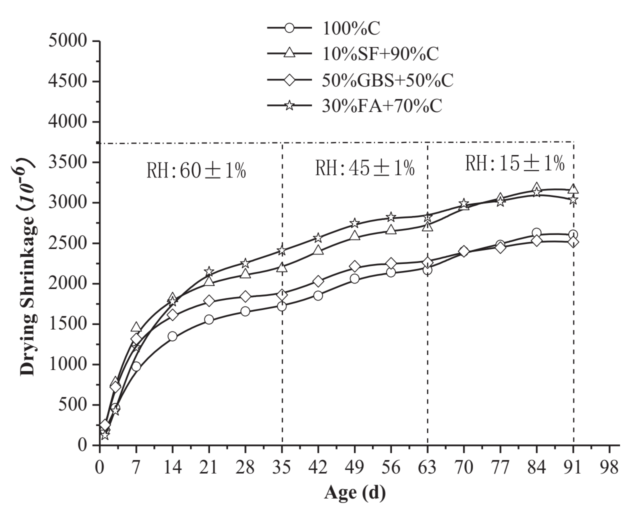

Fig. 1. The influence of mineral admixtures on drying shrinkage of cement paste.

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