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Influence of Restraint on Pore Structures and Air Permeability of Concrete Containing MgO-Type Expansive Agent†

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The effect of restraint on pore structures and air-permeability of concrete containing MgO-type expansive agent was investigated in the paper. Pore structures of mortars in sided center and cubical center of concrete were analyzed using mercury intrusion porosimetry. The porosity and air-permeability of concrete were determined by method of evaporated water and Torrent permeability tester, respectively. The results show that restraint decreases porosity and pore size and improves pore size distribution of mortars in concrete containing MgO-type expansive agent. The improvement of pore structures in concrete matrix tends to increase density and decrease air-permeability of concrete containing MgO-type expansive agent.

Key Words: Restraint, MgO-type expansive agent, Concrete, Pore structure, Air-permeability.

INTRODUCTION

Cracking of concrete induced by its volume shrinkage is one of usual types of damage, which may accelerate other deteriorations and even cause function loss of materials. As a result, more attentions have been paid to reduce and improve volume stability of concrete. Many measures have been suggested to reduce the shrinkage and the shrinkage compensation derived from expansion generated by expansive additives is one of effective measures[1,2]. MgO-type expansive agent is a novel expansive additive, which has advantages of less requirements for wet curing, high stability of the hydration product $Mg(OH)_2$ and easy adjustment of expansion process[3]. Proper expansion generated by MgO-type expansive agent can not only improve volume stability, but also enhance mechanical properties, permeability and freezing-thawing resistance of concrete[3]. Role of MgO-type expansive agent is usually influenced by reactivity of MgO-type expansive agent, curing environment and restrained condition. The relationships among environmental condition, microstructure and property of concrete are not yet fully developed. Research on the relationships between microstructure and property of high performance expansive concrete under restrained condition is absent. The permeability and porosity of concrete have been recognized as major factors in determining durability of concrete structures[4]. This paper reports the effect of restraint on pore structures and air-permeability of concrete containing MgO-type expansive agent.

EXPERIMENTAL

P.II42.5R Portland cement produced by Nanjing-China Cement Corp., Jiangsu, China was used. Coarse aggregate was 5-31.5 mm continuous gradation crushed limestone with 9.5 % smashing index and less than 0.5 % silt. Fine aggregate was river sand with a fineness module of 2.7 and 1 % silt. MgO-type expansive agent and JM-B naphthalene superplasticizer were used as the admixtures. Chemical compositions of cement and MgO-type expansive agent are shown in Table-1. Tap water was used as mixing water.

Mixture proportion of concrete by weight is showed in Table-2. Six concrete cube specimens with size of 150 mm × 150 mm × 150 mm were cast. Half of concrete specimens were demolded at 24 h after concrete was cast. Another half of concrete specimens were not demolded until test was carried. All specimens were directly immersed in water at 20 ± 2 ºC for 365 days.

Pore structures of mortars in concrete were measured by MIP. Mortars in the form of pellets of about 6 mm in diameter were obtained from sided center and cubical center of concretes with restraint and unrestraint. They were then dried in a vacuum oven at 60 ºC for 48 h. Air-permeability of concrete was determined with a Torrent permeability tester[5,6].

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TABLE-1
CHEMICAL COMPOSITIONS OF CEMENT AND MgO-TYPE EXPANSIVE AGENT (MEA) USED (Wt) %

Materials	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	Loss	Total
Cement	21.27	5.16	3.46	64.35	0.95	2.01	0.08	0.55	1.26	99.09
MEA	0.83	0.37	0.80	3.98	91.70	/	/	/	1.98	99.66

TABLE-2
MIXTURE PROPORTION OF CONCRETE BY WEIGHT (kg/m^3)

Cement	Water	Fine aggregate	Coarse aggregate	MEA	Super plasticizer
340	143	610	1425	27.2	2.75

75 mm × 75 mm × 50 mm specimens used for measurement of porosity were cut from concretes. These specimens were thoroughly washed and immersed in water for 48 h. They were removed from water, wiped up for a saturated surface-dry state with a large absorbent cloth and weighed the mass (w_1). Volume of specimens was measured using Archimedes drainage method. These specimens were then dried at 60 ºC and weighed the mass (w_t) once every 0.5 h, up to 7.5 h. They were then dried at 105 ºC to a near constant mass, cooled in air and reweighed the mass (w_2). The water weight loss on drying was converted to volume fraction of the bulk concrete[7,8]. The porosity of concrete was calculated by eqn. (1), the evaporation capacity of water in concrete was calculated by eqn. (2).

$$P = \frac{(w_1 - w_2)}{V\rho} \times 100\ \% \quad (1)$$

$$E = \frac{(w_1 - w_t)}{(w_1 - w_2)} \times 100\ \% \quad (2)$$

where P is the porosity of concrete; E is the evaporation capacity of water in concrete; V is the volume of saturated surface-dry concrete; ρ is the density of water, being 1 g/cm^3.

RESULTS AND DISCUSSION

Effect of restraint on pore structures of mortars in concrete: The influence of restraint and unrestraint on porosity of mortars in sided center and cubical center of concrete containing MgO-type expansive agent is shown in Table-3. In comparison with unrestrained concrete, the porosity of mortar in cubical center and sided center of restrained concrete was decreased by 5.7 % and 1.8 %, respectively. Compared with sided center of concrete, the porosity of mortars in cubical center of concrete with restraint and unrestraint was decreased by 18.1 % and 14.7 %, respectively.

TABLE-3
POROSITY OF MORTARS IN CONCRETE CONTAINING MEA WITH RESTRAINT AND UNRESTRAINT

Samples	Porosity of mortar in cubical center (%)	Porosity of mortar in sided center (%)
Restrained concrete	9.35	11.42
Unrestrained concrete	9.92	11.63

The expansion of cement paste in concrete containing MgO-type expansive agent is caused by the self-expansion of MgO-type expansive agent which is attributed to $Mg(OH)_2$ formation[3]. The results show that restraint decreases porosity of mortars in concrete containing MgO-type expansive agent. Porosity of mortar in cubical center is less than that of mortar in sided center of concrete containing MgO-type expansive agent with restraint and unrestraint, which indicates that there is "self-restricted effect" in concrete. The restricted effect depends upon restrictions of aggregate, especially coarse aggregate[9].

Fig. 1 shows the per cent of pore volume of mortars in sided center and cubical center of concrete containing MgO-type expansive agent with restraint and unrestraint. Pores in mortars may be classified as more harmful pore (pore diameter d > 200 nm), harmful pore (50-200 nm), a less harmful pore (20-50 nm) and harmless pore (d < 20 nm)[10]. The per cent of a less harmful pore of mortars in sided center and cubical center of concrete with restraint and unrestraint exceeds 47 % and the per cent of pore volume of mortar in cubical center is larger than that of mortar in sided center of concrete containing MgO-type expansive agent with restraint and unrestraint, increased by 25.6 % and 7.5 %, respectively. In comparison with unrestrained concrete, the per cent of a less harmful pore of mortar in cubical center of restrained concrete is increased by 13.5 %, the per cent of pore volume with pore larger than 50 nm in diameter is decreased by 19.4 %.

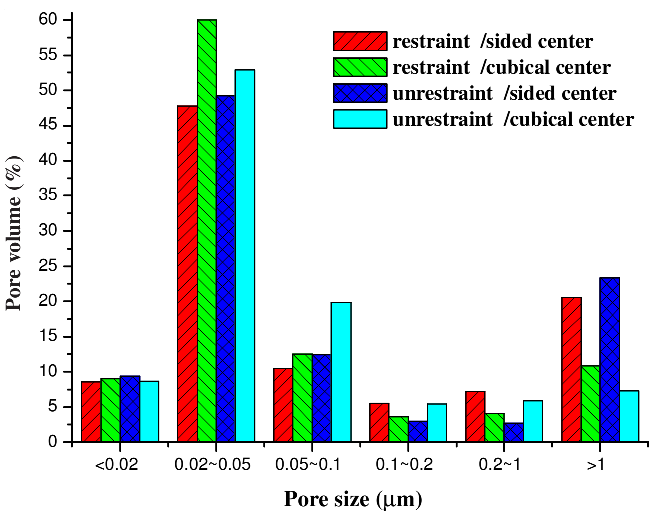

Fig. 1. Percentage of pore volume of mortar in sided center and cubical center of concretes containing MgO-type expansive agent

In comparison with unrestrained concrete, restrained concrete was restricted by steel mould and self-restraint conditions. The per cent of pore volume with pore larger than 50 nm in diameter of mortar in cubical center of restrained concrete is evidently reduced and a little harmful pore is increased. The results indicate that restraint tends to decrease pore size of mortars in concrete containing MgO-type expansive agent.

Effect of restraint on pore and air-permeability of concrete: The effect of restraint on porosity and air-permeability of concrete containing MgO-type expansive agent is shown in Table-4. The water-saturated porosity and air-permeability of concrete were determined by method of evaporated water

TABLE-5
EFFECTS OF RESTRAINT ON EVAPORATION CAPACITY OF WATER IN CONCRETE

Samples	A	B	C	R^{2*}	$E\|_{t=7.5\,h}$ [%]	$t\|_{E=21\,\%}$ [*h*]
Unrestrained concrete /lateral specimens	2.012	4.841	-0.274	0.998	22.89	5.88
Restrained concrete /lateral specimens	2.354	4.509	-0.244	0.996	22.46	6.24
Unrestrained concrete /middle specimens	1.831	4.586	-0.254	0.998	21.95	6.57
Restrained concrete /middle specimens	2.609	4.182	-0.220	0.997	21.61	6.90

*Where R^2 is coefficient of determination

and Torrent permeability tester, respectively. Compared with unrestrained concrete, porosity, permeability coefficient K_t and depth of penetration L of restrained concrete is decreased by 8.3, 8.1 and 7.2 %, respectively.

TABLE-4
EFFECT OF RESTRAINT ON POROSITY AND AIR-PERMEABILITY OF CONCRETE

Samples	Porosity of concrete (%)	Air-permeability of concrete	
		K_T [$\times10^{-16}m^2$]	L [mm]
Restrained concrete	5.08	0.226	32.1
Unrestrained concrete	5.54	0.246	34.6

Quadratic polynomial curves fitting to data points relating evaporation capacity of water in restrained and unrestrained concrete containing MgO-type expansive agent and time are shown in Fig. 2. For the equation of quadratic polynomial curve fitting ($E = A+B \times t + C \times t^2$), assume that t = 7.5 h or E = 21 % respectively, then $E/_{t=7.5h} = A + 7.5B + 56.25C$, or $t\big|_{E=21\%} = \dfrac{-B+\sqrt{B^2-4C(A-21)}}{2C}$, accordingly. Calculational results are given in Table-5.

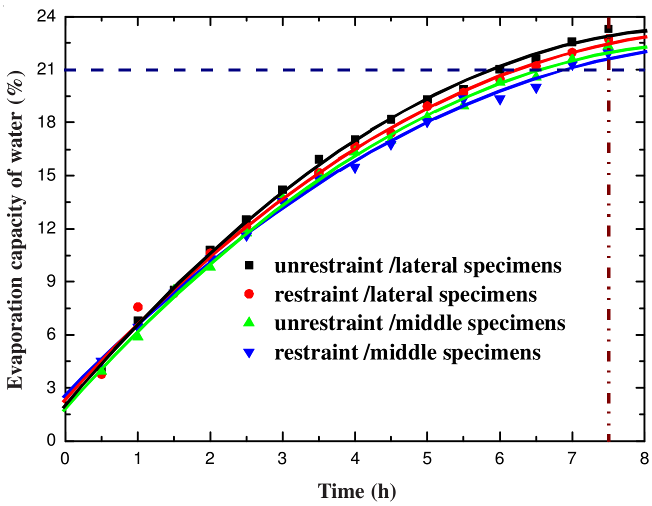

Fig. 2. Evaporation capacity of water at 60°C in concretes

Compared with unrestrained concrete, as concrete was dried for 7.5 h at 60 ºC, evaporation capacity of water in specimens of lateral part and middle part for restrained concrete containing MgO-type expansive agent is decreased by 1.9 % and 1.5 %, respectively. On the other hand, when evaporation capacity of water is 21 %, the time required for evaporation is increased by 6.1 % and 5.0 %, respectively.

The results indicate that restrained concrete containing MgO-type expansive agent shows lower porosity and air-permeability and improvement of pore structures in mortar is consistent with the changing of porosity and air-permeability of concrete.

Conclusion

Restraint may decrease porosity and pore size of concrete containing MgO-type expansive agent. In comparison with unrestrained concrete, the porosity of mortar in cubical center of restrained concrete was decreased by 5.7%, the percent of pore volume with pore larger than 50 nm in diameter is decreased by 19.4 %.

The improvement of pore structures of mortars in concrete may increase density and impermeability of restrained concrete containing MgO-type expansive agent. Compared with unrestrained concrete, porosity, permeability coefficient K_t and depth of penetration L of restrained concrete is decreased by 8.3, 8.1 and 7.2 %, respectively.

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