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Relationship between average pore diameter and chloride diffusivity in various concretes

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Abstract

Since concrete is a heterogeneous composite material which is composed of cement, aggregate, mineral admixture, and so on, the microstructure of concrete is very important to predict transport property associated with the durability of concrete. In this paper, 12 concrete specimens composed of six types of Portland and blended cements with water–binder ratios of 40% and 50% were manufactured to investigate the characteristics of capillary pores using mercury intrusion porosimetry technique and examine measurements of chloride diffusivity in concrete regard to electric potential. The average pore diameter of concretes decreased in the following order: (1) low heat cement, (2) ordinary Portland cement and sulfate resistant cement, (3) blended cement with 40% of slag, (4) blended cement with 60% of slag and, (5) ternary based cement. On the other hand, chloride diffusivity decreased in the following order: (1) low heat cement, (2) ordinary Portland cement and sulfate resistant cement, (4) blended cement with 40% of slag, (3) blended cement with 60% of slag and ternary based cement, indifferently from water–binder ratio. From the result of regression analysis, the chloride diffusivity increased with the average pore diameter presenting a very satisfactory correlation factor exceeding 0.91.

Keywords: Capillary pore; Mercury intrusion porosimetry; Average pore diameter; Accelerated chloride diffusivity

1. Introduction

Concrete, as a quasi-permanent construction material, has been extensively used for structures. If concrete is properly designed and produced for the environment to which it will be exposed, the concrete is capable of maintenance-free performance for decades without any need for protective management. However, problems related to the durability of concrete structures, which exposed to severe environment for long periods, begin to appear. Researches are thus actively performed in Korea as well as in foreign countries to improve the durability of reinforced concrete structures [1–5].

The major factors inducing the degradation of concrete durability are the repetition of freezing–thawing cycles, the alkali-aggregate reaction, the carbonation of concrete, the chemical erosion due to various kinds of deleterious ions and the corrosion of rebar induced by the penetration/diffusion of chloride [6,7]. In other words, degradation of the concrete durability progresses from the pores inside concrete which transfer all kinds of noxious substances like carbon dioxide and chloride as well as water. This phenomenon alters directly and indirectly the performances of concrete and, subsequently, has adverse effect on its durability [8,9].

Pores present in cement solid matrix or in concrete can be distinguished into air voids due to entrained air and air mixed with materials and imprisoned during the mixing and, pores due to mixed water. Pores due

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to mixed water can be divided into gel pores and capillary pores, which, respectively, increase and decrease according to the hydration process of cement, resulting finally in a reduction of the total volume of pore at the end of the process.

Especially, since the structure of the pores in cement matrix depends significantly on the types of cement and admixtures, the maturity that is the degree of hydration of concrete and, the composition of concrete, producing dense cement matrix will contribute effectively on improving the strength as well as the durability of concrete [10].

In the past, the evaluation of micro-porosity in cement matrix has been performed mainly regard to cement paste or mortar. However, the micro-porosity of concrete may differ from cement paste. In other words, concrete being produced by the introduction of fine or coarse aggregates in the cement paste, interfacial zone will definitely be generated between cement paste and aggregates.

In this study, 12 different concrete specimens composed of three types of both Portland and blended cements with various water–binder ratios were manufactured to investigate the quantity and size distribution of pores using mercury intrusion porosimetry technique. In addition, concrete strength and chloride diffusivity in concrete with regard to electric potential were measured, and a correlation between these measurements was examined using regression analysis.

2. Experiments procedure

2.1. Materials and mix proportions of concrete

Ordinary Portland cement (OPC), low-heat Portland cement (LHC), sulfate resisting Portland cement (SRC), OPC with 40% and 60% of ground granulated blast furnace slag (GGBF, converted into G4C and G6C, respectively) and ternary based cement (TBC) blended with GGBF and fly ash (FA) were used in the experiments. Table 1 lists the chemical composition and mineralogical components of the cements and mineral admixtures. Physical properties of cements and concretes in this investigation are shown in Table 2.

River sand, which is immune to most chemical agents and has little organic compounds, was used as fine aggregate and crushed stone with maximum size of 25 mm was used as coarse aggregate for production of all concretes. The specific gravities of fine and coarse aggregates are 2.59 and 2.62, respectively. Physical properties

Table 1
Chemical and mineralogical composition of cements and mineral admixtures

		Cements						Mineral admixtures	
		OPC	LHC	SRC	G4C	G6C	TBC	FA	GGBF
Chemical composition: %	SiO_2	19.88	24.52	22.60	24.68	27.08	36.00	57.60	31.88
	Al_2O_3	4.81	2.85	3.81	7.94	9.51	14.05	25.5	12.64
	Fe_2O_3	3.11	3.52	4.32	2.02	1.48	2.92	6.10	0.39
	CaO	61.56	61.80	62.83	53.92	50.1	36.47	3.40	42.46
	MgO	2.95	2.94	2.54	4.32	5.01	3.71	0.90	6.38
	SO_3	2.82	2.00	2.03	3.14	3.31	2.30	–	3.63
	LOI	2.93	1.01	1.68	2.02	1.56	2.43	4.30	0.65
Mineralogical composition: %	C_3S	54.76	35.39	46.50	–	–	–	–	–
	C_2S	15.68	43.59	29.71	–	–	–	–	–
	C_3A	7.48	1.60	2.79	–	–	–	–	–
	C_4AF	9.46	10.71	13.15	–	–	–	–	–

Table 2
Physical properties of cements and concretes

		OPC	LHC	SRC	G4C	G6C	TBC
Specific gravity		3.15	3.20	3.18	3.06	3.01	2.83
Specific surface area: cm^2/g		3120	3580	3280	3652	3918	3793
Setting time: min	Initial	270	375	290	–	–	–
	Final	400	580	460	–	–	–
Slump: cm	$W/B = 40\%$	13	15	15	14	15	14
	$W/B = 50\%$	14	16	16	15	16	15
Compressive strength: MPa (at 28-day)	$W/B = 40\%$	42.2	39.0	49.4	47.7	45.3	48.6
	$W/B = 50\%$	34.0	27.4	38.2	39.0	34.8	36.2