V－219　Chloride Permeability of Lightweight Aggregate Concrete

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Abstract
Chloride permeability of lightweight concrete mixed with expanded shales as the coarse aggregate was studied and compared with that of normal weight concrete. The chloride permeability of concrete was determined by a chloride permeability test with an electrical potential of 15 volts in which the actual amount of chloride ions passing through a full thickness of the wall of a cylindrical hollow concrete specimen was measured on a regular basis until the constant flow rate of the chloride ions was obtained. This study showed a comparable permeability of chloride ions of lightweight concrete to that of normal weight concrete.

Introduction
With the desirability of weight reduction because of the increasing use of concrete for large span structures and offshore facilities, structural lightweight concrete has been given special attention. For the case of offshore concrete structures, massive concrete members have to be floated from dry-dock to service site, hence lower unit weight of the concrete becomes a key factor. In addition the replacement of deteriorated bridge decks is usually done with lightweight concrete. This is because a reduction in the unit weight of the concrete in the deck allows widening of the roadway deck without requiring additional capacity in the support structures. Little work has been directed to compare the permeability of lightweight and normal weight concrete under similar testing conditions. Considering that future projects will probably make even greater use of structural lightweight concrete, it is important that this work be done.

Experimental Methodology
(1) Specimen Preparation
Lightweight concrete with water-to-cement ratios of 0.4 and 0.6 was made with expanded shale (specific gravity: 1.52, absorption: 12.0 % and maximum size: 12.5 mm) as the coarse aggregate and natural sand (specific gravity: 2.68, absorption: 1.1 % and fineness modulus: 2.68) was used for the fine aggregate. Normal weight concrete with equal water-to-cement ratios was made with natural gravel (specific gravity: 2.68, absorption: 1.0 % and maximum size: 12.5 mm) as the coarse aggregate and the same type of sand used for lightweight concrete was used for the fine aggregate. The lightweight aggregate was presoaked 24 hours prior to mixing. All water-to-cement ratios were calculated on the basis of aggregates being saturated surface dry after 24 hours submersion in water. Mix proportions and physical properties of fresh and hardened concrete are given in Table 1. Cylindrical hollow concrete specimen was cast and its outside and inside diameter is 150 mm and 75 mm respectively with the wall thickness being 37.5 mm. In addition the height of the hollow cylinder is 230 mm. Specimens were stripped at 24 hours and were then cured in a curing room (humidity ＞ 95 %, temperature - about 24 degree C.) for three to four months.

Table 1　Mix proportions and properties of fresh and hardened concrete

Mix	Mix proportions								Fresh concrete			Compression
	W/C	C	W	F.A.	C.A.	S#2	AE	HRWR#3	slump	air	unit wt.	28 days
No.#1		kg/m³				%	mL/m³		mm	%	kg/m³	MPa#4
LW04	0.4	460	184	745	504	46	240	860	115	6.5	1837	35.7 (1.37)
NW04	0.4	460	184	745	888	46	230	530	65	7.0	2298	42.4 (0.40)
LW06	0.6	305	184	876	504	50	50	0	75	6.0	1934	24.7 (0.60)
NW06	0.6	305	184	745	888	50	50	0	75	7.0	2314	27.0 (0.23)

#1:Lightweight and normal weight concrete are abbreviated as LW and NW respectively, the water-to-cement ratios of 0.4 and 0.6 are abbreviated as 04 and 06 respectively. #2: fine and coarse aggregate ratio by volume. #3: Superplasticizer #4: compressive strength (standard deviation)

(2) Chloride Permeability Test with an Electrical Potential - The experimental arrangement is schematically depicted in Fig. 1. An electrical potential difference was 15 volts was applied to the inner and outer curved surfaces of a cylindrical hollow concrete specimen. Under this electrical field chloride ions which initially present in the outside solution of 0.5 N NaCL solution migrate in the concrete wall approaching the positive pole placed in the inside solution of 0.3 N NaOH solution. It was expected that chloride ions electrically forced to transport in the concrete wall began to accumulate in the inside of the sodium hydroxide solution after a certain transition time elapsed. Thus, the content of chloride ions in the inside solution was

periodically measured by the mercuric nitrate titration method until the constant flow rate of chloride ions was attained. This permitted the chloride permeability to be calculated.
(3) Calculation of Diffusion Coefficient of Chloride Ions - The Nernst-Planck equation was used to determine the diffusion coefficient of chloride ions of concrete. The equation developed for this test was given below [1]:

$$D = V_2 \frac{dC_2}{dt} \frac{\ln(r_1/r_2)}{2\pi h \frac{zFV}{RT} C_1} \quad \text{(Eq. 1)}$$

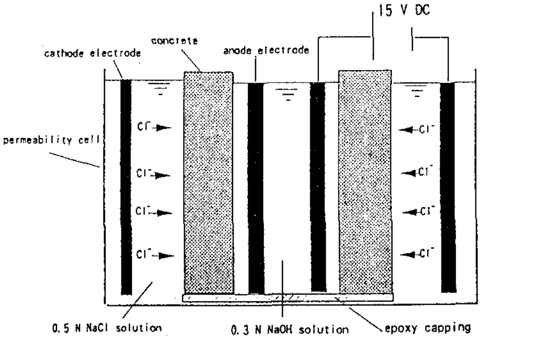

Fig. 1 Schematic representation of chloride permeability test

where D is the diffusion coefficient of chloride ions in unit of cm^2/s, $V_2(dC_2/dt)$ is the flow rate of chloride ions in unit of mol/s and obtained from this electrical test, z is the valency of chloride ions, F is the Faraday constant, R is the gas constant, T is the absolute temperature, V is the applied voltage viz. 15 V, C_1 is the concentration of chloride ions in the NaCl solution viz. 0.5 N, r_1 and r_2 is the outside and inside radius of the hollow cylinder viz. 75 mm and 37.5 mm respectively, and h is the effective height of the specimen.

Results and Discussion

Fig. 2 and 3 show the results of the tests for lightweight concrete and normal weight concrete respectively. It appeared that it took about 7 days until the increase in chloride ions which passed through the concrete became constant in the inside NaOH solution for concrete with water-to-cement ratio of 0.4 and about 2 days for the water-to-cement ratio of 0.6. In order to determine the flow rate of the chloride ions simple regression analysis was conducted using the data after the transition periods. The slope of the line was then used for the chloride flow rate in unit of mol/s for each concrete. The flow rates obtained were 7.27×10^{-7} mol/s, 6.54×10^{-7} mol/s, 15.6×10^{-7} mol/s, and 14.2×10^{-7} mol/s for LW04, NW04, LW06, and NW06 respectively. The diffusion coefficient of chloride ions was calculated in Eq. 1 and was 11.8×10^{-9} cm^2/s, 10.6×10^{-9} cm^2/s, 25.3×10^{-9} cm^2/s, and 23.1×10^{-9} cm^2/s for LW04, NW04, LW06, and NW06 respectively. These values appeared reasonable when compared with others [2]. No significant difference in the diffusion coefficient of chloride ions was found between lightweight concrete and normal weight concrete if the water-to-cement ratio was equal. In addition the diffusion coefficient was to a large extent influenced by the water-to-cement ratio despite types of aggregates used. Therefore the porous nature of the lightweight aggregates had no negative effect on the flow of chloride ions in the lightweight concrete and its chloride permeability was comparable to that of normal weight concrete with equal water-to-cement ratios. The permeability of the mortar matrix which surrounds coarse aggregate particles would play an influential role on the chloride transport in the concrete, which in turn was controlled by the water-to-cement ratios.

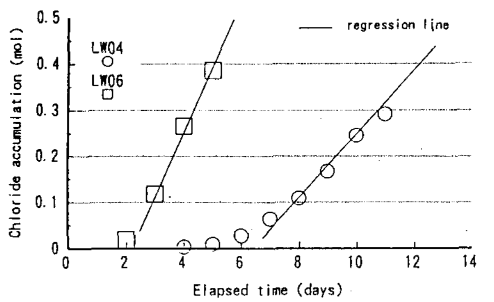

Fig. 2 Increase in chloride ions in NaOH salution

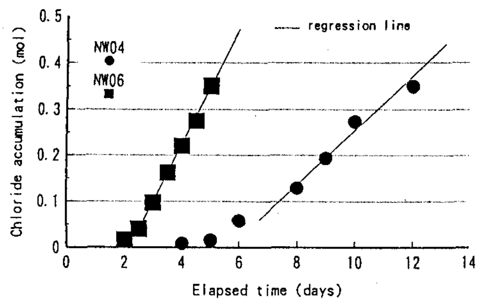

Fig. 3 Increase in chloride ions in NaOH solution

Conclusions

(1)Chloride permeability of lightweight aggregate concrete was comparable to that of normal weight concrete with equal water-to-cement ratios. (2) The electrical method applied to this study was effective in determining the diffusion coefficient of chloride ions of concrete.

References

[1] T. Sugiyama, **Permeability of Stressed Concrete**, A doctoral thesis submitted to the University of New Brunaswick, March, 1994.
[2] The Concrete Society, **Permeability Testing of Site Concrete**, Technical report No. 31, 1987