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PERMEABILITY OF TUNNEL LINING WITH AIR/WATER BUBBLES ON CONCRETE SURFACE

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Air and water bubbles are likely to remain on concrete sidewalls in tunnel linings, because the sidewalls are generally constructed with a greater slope than a right angle. The bubbles negatively influence the aesthetic of the concrete lining. In addition, concrete with a lot of large bubbles may decrease durability, such as air permeability. Although most tunnel lining is constructed as plain concrete without reinforcement, the low permeability may affect the maintenance and long-term durability of the tunnel. The study aims to examine the effect of bubble distributions on the permeability of concrete lining. Concrete specimens including various bubble distributions are prepared by using variable angle-forms in a laboratory test. Furthermore, the bubble distribution (area ratio) and the permeability are examined in two actual tunnels. This paper presents a relationship between bubble distribution and air permeability based on these tests. The results show that the relationship is a logarithmic curve of the bubble rate and gas permeability.

Keywords: Concrete mix proportions, Variable angle concrete form, Durability.

1 INTRODUCTION

To improve the durability of tunnel linings, a porous surface of concrete should be avoided by appropriate construction methods. However, air and water bubbles often remain on the concrete surface of side walls of tunnel linings even with appropriate construction. Figure 1 presents bubbles on the side wall of tunnel lining. These bubbles negatively affect aesthetics as well as durability. Gas (air) permeability on concrete surfaces is an index to quantify the density of concrete without the bubbles. The focus of the present study is to develop an evaluation method of bubbles distributed on concrete surfaces, and to examine the gas permeability of lining concrete with bubbles. To examine the permeability of concrete with bubbles, concrete specimens with various bubble distributions were prepared by using variable angle form. The permeability of test specimens and actual lining concrete were examined and discussed in the current study.

2 METHODOLOGY

2.1 Laboratory Test

To simulate the side wall of a tunnel, a form of variable angle for concrete specimens was prepared. The angle of the concrete mold was set as 30 degrees. Dimensions of the specimen were 750 mm height x 300 mm width x 300 mm length. The evaluated surface of the form was steel with and without grooves. Experimental parameters were the treatment of form-surface, remover and vibrating method. Ceramic coating and water-absorbable sheet were employed for the surface treatment. Tables 1 and 2 give experimental parameters and mixture proportions of concrete, respectively.

Figure 1. Bubbles on the side wall of a tunnel lining.

Table 1. Experimental parameters.

No.	Material	Surface	Remover type	Vibrating method	Mix.I.D
1	steel	-	normal	5points / 15sec.	A
2		-	improved	5points / 15sec.	A
3		ceramic	normal	5points / 15sec.	A
4		ceramic	improved	5points / 15sec.	A
5		ceramic	improved	1point at center / 60sec.	A
6		groove/sheet	improved	1point at center / 30sec.	B
7		ceramic/sheet	improved	1point at center / 30sec.	B

Table 2. Mixture proportion of concrete.

Mix. I.D.	*w/c*	Unit weight (kg/m^3)				
		water	cement	fine aggregate	coarse aggregate	admixture (WRA)
A	0.59	165	280	732	1136	2.80
B	0.59	165	280	726	1136	2.24

2.2 Field Test

Lining concretes of two NATM tunnels were examined as well as those in the laboratory test. Material of the form is also steel for both tunnels. Table 3 summarizes the parameters of the actual lining concrete in the field test. In addition, Table 4 gives mixture proportions of lining concrete.

Table 3. Lining concrete.

No.	Tunnel	Surface	Mix.I.D.
8-11	A tunnel	groove/sheet	C
12,13	A tunnel	groove/sheet	D
14	A tunnel	normal	C
15,16	A tunnel	normal	D
17-24	B tunnel	normal	D

Table 4. Mixture proportions of lining concrete

Mix. I.D.	*w/c*	Unit weight (kg/m^3)				
		Water	cement	fine aggregate	coarse aggregate	admixture (WRA)
C	0.486	175	360	900	864	3.60
D	0.566	167	296	814	1021	3.14

2.3 Measurement

2.3.1 *Air/water bubbles rate on concrete surface*

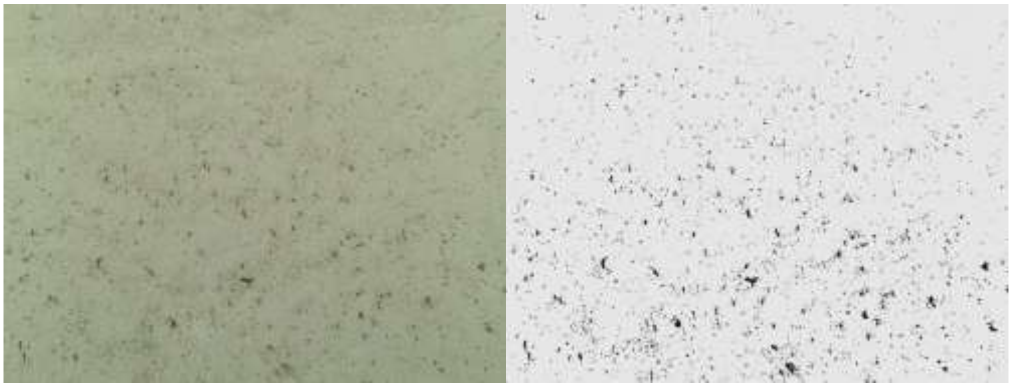

Figure 2. Photographic and monochrome image for analysis.

Air/water bubbles distributed on concrete surface were evaluated by a photographic image analysis (Hirano *et al.* 2014). To make clear the air/water bubbles, the photographic image was converted to a monochrome image. Figure 2 demonstrates the photographs used in the analysis. The black in the monochrome image presents the bubbles. A bubble ratio can be estimated from the number of pixels of bubbles divided by all pixels.

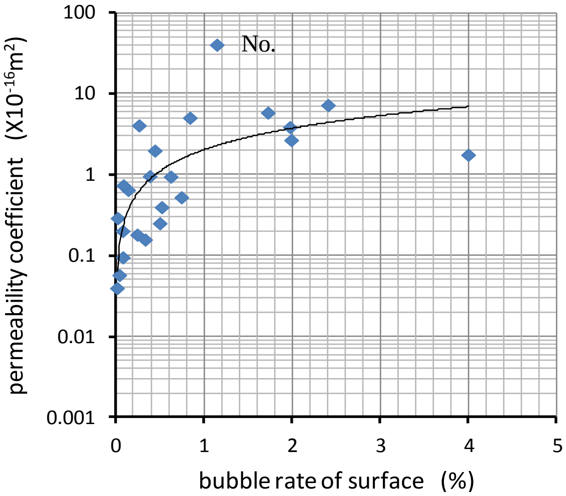

Figure 3. Relationship between the permeability coefficient and the bubble rate (laboratory and field tests).

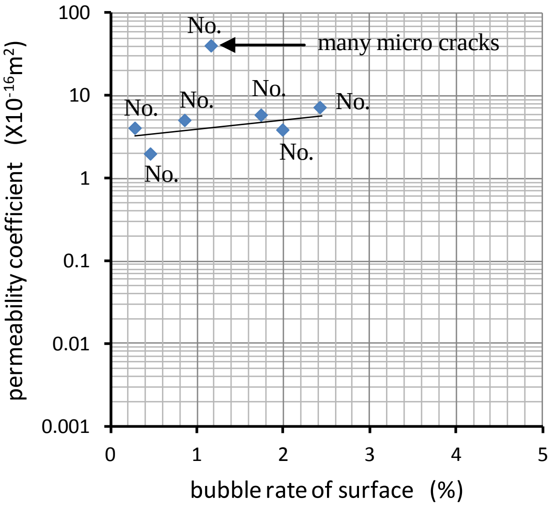

Figure 4. Relationship between the permeability coefficient and the bubble rate (laboratory test).

2.3.2 *Gas permeability*

To discuss the durability of concrete with bubbles, air permeability was examined by the Torrent method (Torrent 1992). The permeability test was performed in the actual lining concrete in addition to the laboratory test. The test was conducted three times at each measurement point.

3 RESULTS AND DISCUSSION

Figure 3 presents the relationship between the permeability coefficient and the surface bubble rate of the objective concrete in this investigation. The result of specimen No. 3 was considerably greater than other results, because many micro cracks occurred on the surface. A regression curve can be obtained from the results except for the result of No. 3. It was confirmed that the permeability coefficient increases logarithmically in accordance with the increase of surface bubble rate. The permeability coefficient of specimens is greater than the coefficient in actual tunnel lining, because a lot of air bubbles on the surface.

Figure 4 shows the relationship between the permeability coefficient and the surface bubble rate by only employing the results in the laboratory test. The surface bubbles rate also decreases with a decrease in the permeability. Both have an equilateral correlation. Above all, the surface-bubble rate of specimens No. 6 and 7 is smaller than others, and the permeability is smaller, too. These test pieces were made by a form-coating permeance sheet. The coating sheet can contribute to reducing air bubbles on and increase the density of concrete surfaces. The observation confirms that the form surface affects the aesthetic and durability of concrete. The surface bubble rate and permeability in No. 5 are smaller than the values of other specimens (No. 1, 2, and 4). It is noteworthy that the significant decrease of bubbles and low permeability coefficient were observed in the test specimens (No. 5, 6, 7) made with longer vibrating.

4 CONCLUSIONS

The focus of this study was to improve the aesthetic and durability of lining concrete at construction, and to quantify the relation between these factors. In particular, the study focuses on the relation between bubble rate and permeability on concrete surface. The conclusions of this investigation follow:

(1) Gas permeability is influenced by the air/water bubbles distributed on the lining concrete. A logarithmic regression curve of bubble rate and permeability was found in the laboratory and field tests.

(2) Form materials may affect the aesthetic and durability of lining concrete.

(3) The vibrating work is an important factor to improve aesthetic and durability. Concreting with long vibration contributes to reducing bubbles and decreasing the permeability coefficient.

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