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Evaluation of Air Void System and Permeability of Latex-Modified Concrete by Image Analysis Method

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Abstract: Addition of latex to concrete is known to increase its durability and permeability. The purpose of this study is to analyze air void systems in latex-modified concretes using a reasonable and objective method of image analysis with such experimental variables as water-cement (w/c) ratios, latex contents (0%, 15%) and cement types (ordinary portland cement (OPC), high-early strength (HES) cement and very-early strength (VES) cement). The results are analyzed by spacing factor, air volume (content) after hardening, air void distribution and structure. Additionally, air void systems and permeability of latex-modified concrete (LMC) are compared by a correlation analysis. The results are as follows. The LMC of the same w/c ratio showed better air entraining (AE) effect than OPC with AE water reducer. The VES-LMC showed that the quantity of entrained air below 100 μm increased more than four times. For the case of HES-LMC, microscopic entrained air between the range of 50 to 500 μm increased greater than 7 times even in the absence of anti-foamer. Although spacing factor was measured rather low, the permeability of latex-modified concrete was good. It is construed that air void system does not have a considerable effect on the property of latex-modified concrete, but latex film (membrane) has a definite influence on the durability of LMC.

Keywords: image analysis method, latex modified concrete, anti-foamer, air void, permeability

1. Introduction

The inside structure of concrete generates air void due to the compositeness of the materials used and the mechanical effect during its preparation, and this air void affects directly and indirectly the manifestation of concrete performance after its hardening. When the air void inside typical concrete becomes excessive, it can cause deterioration of strength and cracking. On the other hand, if it is too small, it is known to decrease the durability of the concrete.[1-3] Thus, it is specified to maintain an appropriate amount of air content with the addition of AE agent, AE water reducer, etc.[2] Nonetheless, even if the concrete has the same amount of air void content, its durability such as anti-freezing thawing property, surface scaling resistance, permeability, etc. varies greatly with the distribution of the air void size and the structure of the air void inside the concrete such as the ratio of entrapped air void to entrained air void. However, it is the current situation that the evaluation of concrete for the purpose of obtaining durability is limited to the evaluation of total air content for fresh concrete.

One method to approach and analyze the air void structure inside the concrete for the durability evaluation systematically is to measure the distance between air voids, called spacing factor, and it has been recommended to maintain the maximum distance between the air void at or less than 250 μm for the purpose of obtaining the desired durability.[3,4]

Currently, latex-modified concrete (hereinafter, LMC) and very-early strength latex-modified concrete (hereinafter, VES-LMC) are being applied widely as the surface overlay material for new bridge and surface pavement repair material for existing bridge in Korea since 2001.[5,6] Additionally, high-early strength latex-modified concrete (HES-LMC) is being developed for the purpose of using it as a repair material for the structures requiring water impermeability. Although the evaluation of durability for these LMC's has been reported, the research to investigate the durability of LMC's in relation to the air void structure inside these LMC's has hardly been carried out. Especially, since the structures targeted by LMC's is highly related to water permeability resistance, it can be safely said that the investigation of the relationship between permeability and the change in the air void inside the concrete is very important. However, it is current practice in Korea to apply the specification for the air content set for the ordinary concrete, ignoring the change in the air void inside the concrete due to the mixing of latex polymer.

Thus, this study aimed to investigate and analyze systematically the change in air void structure and its characteristics caused by mixing of latex polymer particles through the evaluation of the change in the air void structure inside the latex-modified concrete with respect to different types of cement. Accordingly, air content inside the concrete, the distribution of air void by the size, condition of the air void structure and spacing factor were evaluated for this research objective. In addition, the air void structure inside the concrete and permeability of LMC were analyzed and compared to investigate their relationship.

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2. Experimental plan and method

2.1 Experimental plan

This investigation selected the type of cement and latex mixing or no-mixing as important variables of the experiment in order to examine the relationship of permeability with respect to the change in the void structure inside the latex-modified concrete. Image analysis method was used to investigate the microstructure of the concrete after hardening, and chloride ion infiltration rate was measured to evaluate the durability of various types of concrete. The image analysis method is advantageous in that it can analyze the air void structure of the concrete test specimen across all cross-sections. The minimum diameter of the air void, that can be analyzed by this method, is about 5~10 μm, and this is due to the limitation of current analysis equipment. The formation of air void less than this size (in the magnitude of nanometers) is caused by the hydration of the cement, and the formation of air void inside the concrete can be controlled by mixing of AE agent, AE water reducer, latex, etc. Thus, this study aimed to analyze the characteristics and the change in air void structure in response to the mixing or no-mixing of AE water reducer and latex using image analysis method.

2.2 Materials

2.2.1 Cement

Three kinds of cement - ordinary portland cement (OPC), high early strength cement (HEC) for early strength development, and very early strength cement (VEC) for the shortest time of strength development, were used to analyze the characteristics of air void structure after hardening of these thee types of cement.

Table 1 summarizes physical and chemical compositions of the cement used for this research.

2.2.2 Aggregate

Crushed stone for ready-mix concrete was used as the coarse aggregate of maximum size of 25 mm and 13 mm, and its specific gravity and absorption coefficient was measured at 2.6 and 0.71, respectively. Natural riverside sand from Hongcheon River with specific gravity of 2.7 and absorption coefficient of 0.97 was used as the fine aggregate.

Table 1 Physical and chemical compositions of cement used.

Cement types	Chemical composition (%)					Blaine fineness (cm^2/g)	Specific gravity
	SiO_2	Al_2O_3	Fe_2O_3	CaO	SO_3		
OPC	20.8	6.3	3.2	61.2	2.3	3,200	3.15
HEC	19.7	5.9	3.0	62.1	4.2	4,400	3.12
VEC	10.2	16.7	1.3	50.8	15.5	5,400	2.90

2.2.3 Latex

SBR latex from D company in the USA was selected for this study. It is composed of styrene and butadiene in the ratio of 66 : 34, and its overall structure is liquid with 52% water, 48% polymer powder, and a small quantity of interface activating agent and stabilizer.

2.2.4 Mix design

LMC and VES-LMC used in this study were mixed pursuant to the specified mix-proportion table being applied to current domestic bridge surface pavement,[6,7] and the mixing or no-mixing of 15% latex was selected for the variable of the experiment to examine the change in the air void structure inside the concrete. Additionally, water-cement ratio and addition or no-addition of anti-foamer were varied to bring about the change in the air void structure inside the concrete in order to analyze the performance of latex-modified early strength concrete, which is being currently developed as repair materials for typical structures. Detailed mix proportion of the latex-modified concrete is shown in Table 2.

2.2.5 Preparation of test specimen

One test specimen was prepared for the analysis of both air void microstructure and permeability of LMC's at the same time in order to minimize the experimental errors caused by heterogeneity of different test specimens. A test specimen of ø100×200 mm size was prepared and cured and then was cut to 50 mm thickness in order to carry out an image analysis and chloride ion permea-bility test on the same test specimen. Curing of the specimen was carried out for 28 days under the controlled environment of relative humidity of 80% and temperature of 20°C.

2.3 Experimental method

2.3.1 Rapid chloride ion permeability

The evaluation of concrete permeability was conducted by the rapid chloride ion permeability test as specified by KS F 2711

Table 2 Mix proportion of latex-modified concretes.

Type	W/C (%)	S/a (%)	Unit weight (kg/m^3)					Ad. (%)	Gmax (mm)
			C	W	L	G	S		
OPC	33	58	400	132	-	795	1,033	2.5*	13
LMC	33	58	400	67	125***	728	946	-	
VEC	38	58	390	148	-	789	1,031	-	13
VES-LMC	38	58	390	43	122	918	707	1**	
HES-LMC	34	50	400	71	125	891	809	-	13
	35	50	400	73	125	888	806	0.5**	
	31	50	400	59	125	908	824	-	25
	32	50	400	61	125	905	821	0.5**	

* : Air entrained water reducer, ** : Anti-foamer

*** : Latex solid ratio for unit weight cement : 400 × 0.15 = 60 kg/m^3, Latex content = solid : water = 60 : 65 = 125 kg/m^3

(2002).[8] The rapid chloride ion permeabitity test has the advantage of determining permeability resistance of the experimental subject in a shorter time than forced permeability test. In other words, the permeability test to determine the permeability coefficient by Darcy's law infiltrates water into the experimental structure, and it requires an excessive time to determine the permeability coefficient due to the small amount of water for the case of densely packed concrete structure, large-size equipment, and the complexity of the experiment. Fig. 1 illustrates the rapid chloride ion permeabitity test equipment.

The equipment has an electric circuit to provide a stable direct current of 60 ± 0.1V. During the experiment, a rubber water-proof material was used to prevent the leaking of the solution, and the electrode receptacle and the test specimen were stabilized by 20~40 g in between. A method to measure the current is to connect a resistance to the circuit to measure the voltage, and a resistance of 0.2Ω was used in this experiment. The exposed part of the concrete specimen was shielded with impermeable material to prevent drying of the concrete surface and infiltration of chloride ion.

Fig. 2 depicts a vacuum device to make the inside of the test specimen vacuous prior to the experiment. This vacuum installation is a necessary process for the permeability experiment and is a factor of influence on the flow of the solution to permeate inside the test specimen. An accurate test result can be attained only when pure air void uncontaminated by other materials is left.

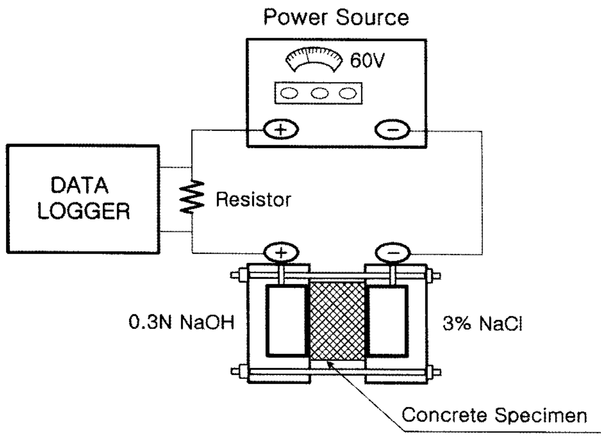


Fig. 1 Permeability equipment.

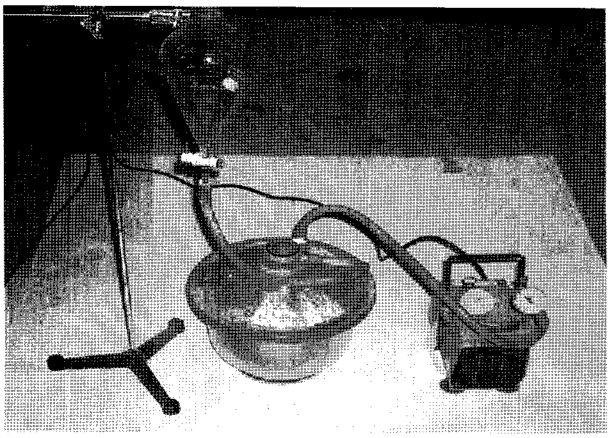


Fig. 2 Vacuum installation.

Additionally, distilled water should be used as the water used for the permeability test. If a solution other than distilled water is used, the impurities dissolved in the solution can disturb the flow of the ions between the electrodes to lower the reliability of the experimental result. Thus, this study employed such a vacuum device to make the inside of the test specimen vacuous and used distilled water for the permeability experiment. KS F 2711 specification rates the permeability of the concrete by the measured amount of electric charge as shown in Table 3.[8]

2.3.2 Image analysis device for the evaluation of air void system

Several researchers investigated the microstructure of air void inside the concrete using image analysis.[9-12] Reviewing their research findings, they reported this method could analyze the microstructure more accurately and faster than the method specified by ASTM C 457. It has an additional advantage of analyzing the microstructure of the concrete automatically by a computer to obtain such detailed information as the distribution of the air void diameter, the form of the air void, the ratio of air void distribution, etc. compared to the ASTM method.

The image analysis device consisted of a conventional microscope manufactured by D company (model OSM-1), a digital camera (N digital camera : Coolpix 5000), a computer, and an accessory supporting table moveable vertically and horizontally to move the test specimen easier. Then, the image was analyzed by an image analysis program coded by O company (TDI Scope Eye-TDI Package). The magnification for the analysis of the test specimen is 20-power. When a camera image is input to the image analysis program, it is digitalized as an image of 2560×1704 pixels. This in turn represents an area of about 57.25 mm^2 or 9.275 mm×6.173 mm. Thus, at this magnification, one pixel is the size of 3.6 μm.

2.3.3 Image analysis method

The test specimen used for the image analysis is a cylindrical object of ø100×200 mm size, and it has been cut to 50 mm length to make the analysis easier. When cutting the test specimen, care must be taken to cut it perpendicularly so that the cut surface is smooth and even and not to cause strata or inclination of the cut surface due to a variation in the cutting speed. The test specimen right after cutting has so very rough face that the air void area is difficult to distinguish. Moreover, the processing of its surface in the next stage is difficult. Thus, the cut surface of the concrete is polished with SiC powder. The SiC powder was used for the surface polishing as the abrasive at the 60th, initially, 100th, 200th, 320th, 420th, and the 600th, finally, polishing process.

After polishing, when the required smooth section of the test specimen is obtained, a water jet spray is used to remove the

Table 3 Permeability rating by KS F 2711.

Coulombs(Q)	Permeability rating
above 4,000	High
2,000~4,000	Moderate
1,000~2,000	Low
100~1,000	Very low
100 below	Negligible

impurities inside the air void of the test specimen section to wash away the surface. After the surface polishing is finished, the test specimen is fully dried, and a water-soluble black ink is painted over it. When the black ink paint is dried fully, a white powder is pressed in onto the surface of the test specimen so that the air void in the surface of the specimen is filled with the white powder. Thereafter, the surface of the test specimen is partitioned for the image taking by a digital camera and a microscope. The images are then analyzed by a computer. The image processed through the computer program is analyzed right away, and such data as the average, maximum, and minimum diameter, and area of each air void, the total and average area of the air void in a given image, the ratio of the air void, etc. are measured and analyzed as required by the experiment. Such analyzed data are stored as an Microsoft Excel file, and various measuring variables are computed through the combination of necessary measured items.

3. Experimental results and analysis

3.1 Latex-modified concrete mixed with ordinary Portland cement (LMC)

3.1.1 Analysis of air void system status

Fig. 3 illustrates the change in the air void structure by the mix ratio (15%) of the latex. The analysis of air content inside the hardened concrete was conducted by classifying the air void into entrained air void and entrapped air void based on the diameter of the air void at 1,000. ASTM C125 defines the entrapped air void as irregular shape and greater than 1,000 μm in diameter as in Fig. 4(a) and the entrained air void as close to round shape and 10~1,000 μm in diameter as in Fig. 4(b).[3] Thus, this study also followed this standard to classify the entrapped air void and entrained air void based on the diameter of the air void at 1,000 μm for the purpose of evaluating the air void structure inside the concrete.

From the experimental result as summarized in Fig. 3, mixing of latex results in greater distribution of entrained air void (air void diameter below 1,000 μm) and greater ratio of entrained air void among all air void distribution given the same mixing condition except the latex addition or absence of it.

Although the total air content of ordinary concrete with AE water reducer was about 5% to meet the standard for the specification, air content of entrapped air void was about twice that of entrained air void based on the analysis of the characteristics of its air void. This is deemed mainly due to the characteristics of mixing applied in this research than that of AE water reducer. In other words, low ratio (33%) of water to cement resulted in inadequate interfacial activation during the mixing and preparation process for the test specimen to cause relatively more entrapped air void (characteristics of dense mixing - less water) than entrained air void.

Fig. 5 shows that, as latex is added, air void of microstructure (about 300 ~700 μm diameter) increases greatly. This is construed to be due to more entrained air void caused by such interfacial activators as emulsifier and stabilizer contained in latex.[10]

The result of analysis of air void structure inside the concrete after the addition of latex indicated that latex addition resulted in greater entrained air void compared to AE water reducer given all the other mixing condition was set the same. Additionally, the latex polymer resulted in drastic increase in entrained air void below 1,000 in diameter, and the entrained air void amounted to more than 70% of all air void content inside the concrete specimen.

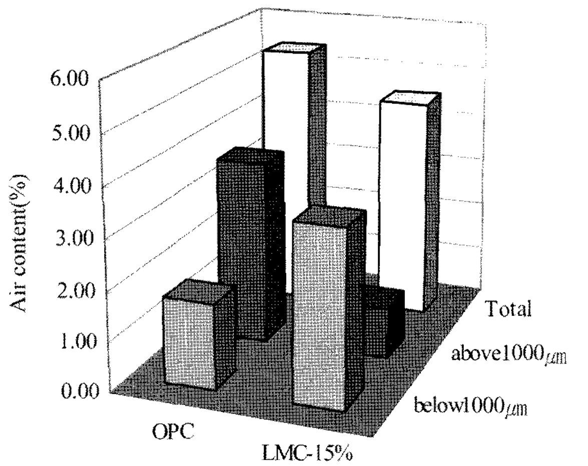
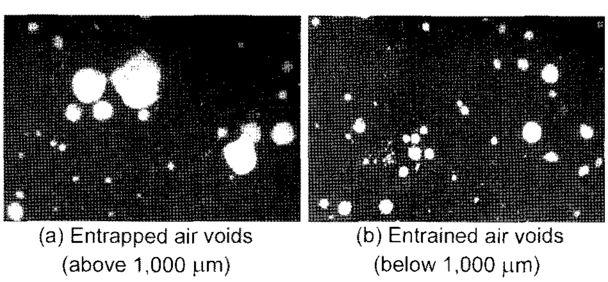


Fig. 3 Comparison of air content for LMC.



(a) Entrapped air voids (above 1,000 μm) (b) Entrained air voids (below 1,000 μm)

Fig. 4 Distribution of air voids.

3.1.2 Correlation between spacing factor and permeability

Table 4 shows the result of an image analysis for spacing factor and permeability of the concrete as measured by chloride ion permeability. At 28 days, the permeability of OPC and LMC showed 4,000 and 1,500 coulombs, respectively. Addition of latex resulted in about three-times greater permeability given the same mixing condition. Additionally, the air content inside the concrete was 5.4% for OPC and 4.5% for LMC. However, spacing factor for LMC with less air void content was measured

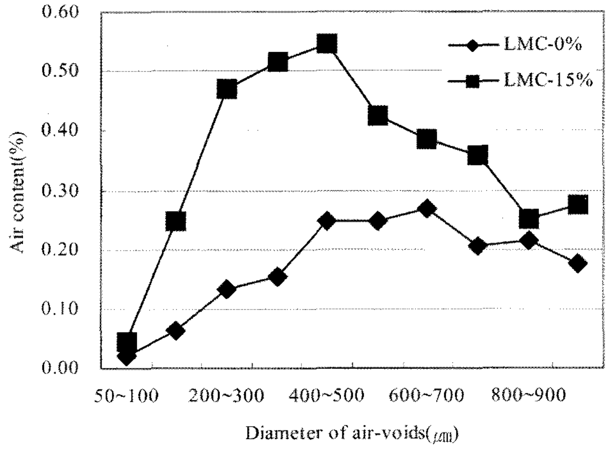


Fig. 5 Air voids distribution of LMC.

Table 4 Spacing factor of OPC and LMC.

Types of concrete	W/C (%)	Latex (%)	Coulombs	Air content (%)	Spacing factor (μm)	Curing time (days)
OPC	33	0	4,000	5.43	601	28
LMC	33	15	1,525	4.54	405	

at a lower value of 405 μm. This can be explained by the following facts. As shown in Table 5, although air content of LMC is less than that of OPC, the number of air void for LMC is 3,490, which is about three times that for OPC measured to be 1,361. Thus, as the spacing factor is represented and computed by the distance between air void, it was rather lower for LMC. In other words, interfacial activation by latex polymer particles resulted in greater number of microscopic air void and, thus, smaller distance between air void.

However, this distance factor between air void did not greatly affect the evaluation of permeability and instead enhanced the permeability resistance. The case of LMC with shorter distance between air void exhibited higher permeability resistance than the case of OPC with greater distance between air void, which is used for the route of water (moisture) flow. This is construed to be due to the characteristics of LMC, and the film membrane between latex polymer as formed within the concrete builds up an impermeable layer so as to restrain the flow of water (moisture) through the air void.

3.2 Latex-modified concrete mixed with high early strength cement (HES-LMC)

3.2.1 Analysis of air void system status

Examining the result of the analysis of air void structure for latex-modified concrete mixed with high early strength cement, the number of microscopic (50~500 μm diameter) entrained air void increases drastically with the mixing of latex as shown in Fig. 6. Here, G and AF denote the maximum size of the coarse aggregate and the amount of added anti-foamer, respectively. The increase in entrained air void inside concrete is directly related to the improvement in workability and anti-freezing thawing property. HES-LMC with anti-foamer exhibited a conspicuous decrease in entrained air void below 1,000 μm in diameter. However, its anti-foaming (air void) effect on entrapped air void with over 1,000 μm in diameter was minimal. While the entrapped air void over 1,000 μm in diameter amounted to only about 1% of total air void content, the amount of entrained air void below 1,000 μm in diameter varied with the addition of latex and anti-foamer. Thus, the control for the amount of entrained air void is possible. Fig. 7 (a) and (b) shows the distribution of microscopic air void below 1,000 μm in diameter. It shows that the number of very microscopic air void within the range of diameter between 50~500 μm increased with the addition of latex, and thus the ratio of these increased microscopic air void in turn becomes greater. From these results, it was found that latex addition brought about the increase in total air content and that the entrained air void within 50~500 μm range of diameter is very effectively distributed among all air void inside the concrete.

Table 5 Result of air voids system of LMC.

	OPC	LMC
Number of air void	1,361	3,490
Average area of air void (μm^2)	278,806	94,026
Air content (%)	5.43	4.54
Spacing factor (μm)	601	405

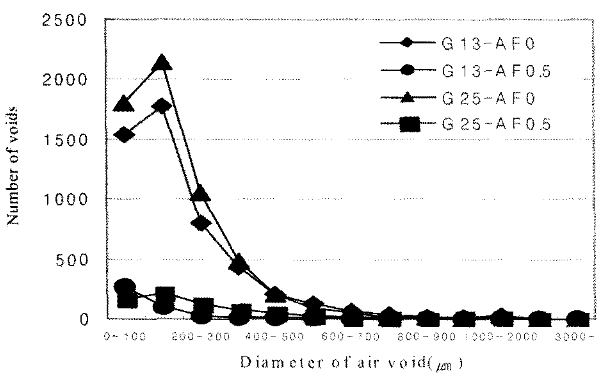
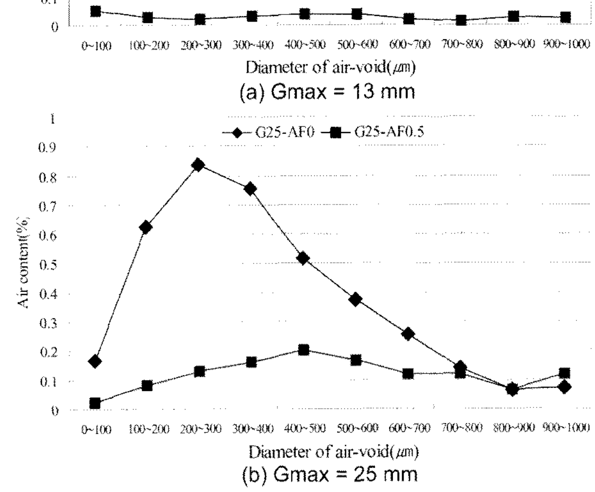


Fig. 6 Distribution of number of air voids for HES-LMC.

3.2.2 Correlation between spacing factor and permeability

The analysis of air void structure inside the latex-modified concrete mixed with high early strength cement showed that the number of very microscopic air void within 50~500 μm range of diameter increased drastically with the addition of latex and that the overall air content increased accordingly. In addition, the addition of anti-foamer decreased the number of microscopic air



(a) Gmax = 13 mm

(b) Gmax = 25 mm

Fig. 7 Air voids distribution of HES-LMC.

void and overall air content correspondingly due to the effect of air void destruction and suppression. A chloride ion infiltration (penetration) resistance test was carried out in order to investigate the permeability characteristics of the concrete in response to this change in the air void structure.

Table 6 shows the change in total air content and permeability test result for HES-LMC. Examining the spacing factor by the characteristics of air void, the air content was measured at 4.73% and 4.64% for the case of latex-modified concrete with maximum coarse aggregate size of 13 mm and 25 mm, respectively. Its corresponding spacing factor (the distance between air void) was measured at 318 μm and 281 μm, respectively. However, the total air content was lowered to below 3% with the addition of anti-foamer given all other conditions kept the same, and the spacing factor for this HES-LMC with anti-foamer was measured at 642 μm and 841 μm for the maximum coarse aggregate size of 13 mm and 25 mm, respectively.

Analysis of the evaluation of the relationship between air void characteristics and permeability revealed that, although there was a difference in permeability by the maximum size of coarse aggregate at 7 days of concrete aging, the permeability did not show any difference with respect to all variables at 28 days of concrete aging. That is, all cases of lowering the air content below 3% with the addition of anti-foamer, changing the spacing factor to over 600 μm, and changing the spacing factor to about 300 μm with the addition of latex only showed the permeability between 1,000~2,000 coulombs based on the result of chloride ion permeability (infiltration) resistance test.

If this point is to be analyzed in more detail, the total number of air void was about 5,000 with the addition of latex and so distributed, but it decreased to about one tenth of the original quantity.

Although there was a change in spacing factor due to the change in the number of air void, it was so evaluated that this change was not related to the permeability of the concrete inside. This observation was construed to be due to the constraint of the permeability itself by the formation of latex film membrane of independent impermeable layer inside the concrete with the addition of latex regardless of the condition of the air void. Thus, it was found that the latex-modified concrete had a very low relationship between the permeability and the characteristics of the air void inside the concrete unlike ordinary concrete.

3.3 Latex-modified concrete mixed with very early strength cement (VES-LMC)

3.3.1 Analysis of air void system status

Previous studies reported that VES-LMC exhibited better effect when an appropriate amount of anti-foamer is added during the latex mixing.[5,6] Thus, this study investigated the influence of anti-foamer addition in the amount of 1% of latex. Fig. 8 shows and compares the air content of VEC and VES-LMC as analyzed by an image analysis method. The air content for the case of VEC, which does not have the addition of latex, was measured at the cross section to be about 3.6% after hardening of the concrete while the air content of VES-LMC mixed with latex was measured to be lower at 2.5%.

Although latex is known to have the effect of improving workability and air entraining agent due to the action of such interfacial activators as emulsifier and stabilizer, it is deemed that VES-LMC has lower air content due to the influence of anti-foamer during the mixing.

The rather high air content of VEC without AE water reducer

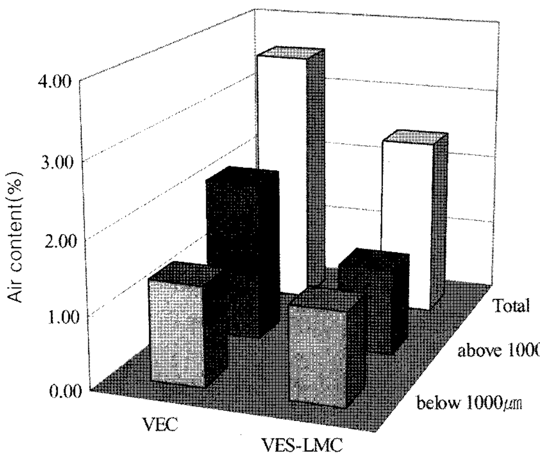


Fig. 8 Comparison of air content for VES-LMC.

Table 6 Spacing factor of HES-LMC.

Type of concrete	W/C (%)	Latex (%)	Coulombs		Air content (%)	Spacing factor (μm)
			7days	28days		
G13-AF0	34	15	4,300	1,800	4.73	318
G13-AF0.5*	35	15	4,600	2,000	0.92	841
G25-AF0	31	15	1,800	1,000	4.64	281
G25-AF0.5	32	15	2,200	1,500	2.41	642

*G13 : Gmax 13 mm, AF0.5 : Antifoamer 0.5%

Table 7 Air voids system of HES-LMC.

	G13-AF0	G13-AF0.5	G25-AF0	G25-AF0.5
Number of air void	5,041	452	5,888	735
Average area of air void (μm^2)	59,318	107,565	46,877	143,648
Air content (%)	4.73	0.92	4.64	2.41
Spacing factor (μm)	318	841	281	642

was contributed to the lack of a densely packed structure due to the thick mix proportion of low water-cement ratio. This point is supported by very high air void inside the concrete with the diameter over 1,000 μm as shown in Fig. 8 of comparing the air content of entrained air and entrapped air.

Nevertheless, VES-LMC showed enhanced fluidity with the addition of latex, and the formation of excess air void was restrained owing to the air void destruction by anti-foamer.

3.3.2 Correlation between spacing factor and permeability

Table 8 summarizes the results of chloride ion infiltration (penetration) resistance test and analysis of the air void structure inside VEC and VES-LMC.

The figure shows that the inside air content and permeability of VEC are 3.56% and 710 coulombs, respectively. VES-LMC exhibited very high permeability resistance as shown by inside air content of 2.52% and permeability of 127 coulombs. Although this result can be construed by the reduction of permeability due to the decrease in the air content inside the concrete, the following interpretation is possible based on the relationship between spacing factor and permeability.

First of all, the spacing factor between air void inside VEC was measured at 534.4 μm, and that inside VES-LMC was lower at about 270 μm despite low air content. This difference in the spacing factor of the inside air void is not simply due to the difference in air content, and it is mainly attributed to the number of air void as indicated in Table 9. Although VES-LMC had the total air content reduced by the use of anti-foamer compared to VEC, the number of entrained air void below 100 μm in diameter increased conspicuously as shown in Fig. 9.

Despite the fact that the total air content decreased due to the increase in the number of such microscopic entrained air void, the spacing factor between air void was evaluated to be lower than VEC. In addition, the resistance to the permeability of VES-LMC was better than VEC despite its lower spacing factor.

Examining the relationship between permeability and spacing factor as shown in Fig. 10, its relationship is inversely proportional for both VEC and VES-LMC. This result is due to the addition of latex, and the relationship between spacing factor and permeability for LMC is influenced more by the impermeability of latex film membrane formed by the addition of latex than by the spacing factor between air void inside the concrete.

4. Conclusion

The following conclusions are derived from the relationship between permeability resistance and such various characteristics of air void inside the concrete as air content, air void distribution by the diameter size, spacing factor, etc. with the research objective of evaluating the characteristics of air void structure inside the latex-modified concrete by various cement types after its hardening.

1) Latex-modified concrete exhibited better entraining air void effect compared to ordinary Portland cement with AE water reducer given the same water-cement ratio. Additionally, although the number of microscopic entrained air void increased by the addition of latex to shorten the distance between air void, the permeability resistance varied inversely proportional and increased on the contrary. Thus, the permeability and spacing factor between inside air void offset each other, and their relationship was found to be insignificant.

2) Although the air void structure inside the concrete varied with the addition of latex and anti-foamer regardless of the maximum size of coarse aggregate for HES-LMC, its relationship between spacing factor and permeability was insignificant as well.

3) The total air content of VES-LMC was measured lower due to the addition of anti-foamer compared to VEC without latex addition. However, its spacing factor was measured lower

Table 9 Air void system of VES-LMC.

	VEC	VES-LMC
Number of air voids	1,708	7,291
Average area of air void (μm²)	147,036	25,344
Air content (%)	3.56	2.52
Spacing factor (μm)	534	274

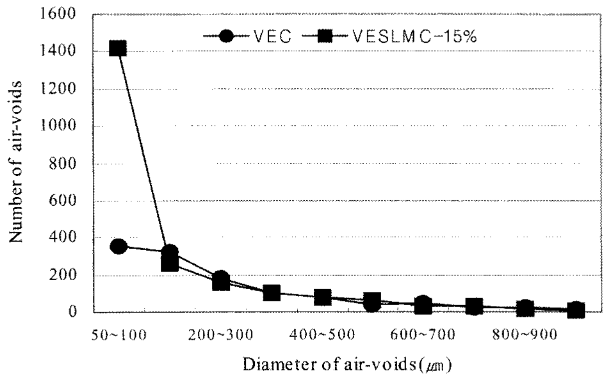


Fig. 9 Distribution of air voids in numbers at VES-LMC.

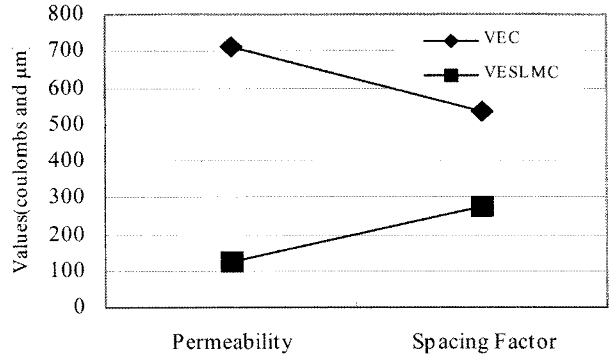


Fig. 10 Relationship of permeability and spacing factor for VES-LMC.

Table 8 Spacing factor of VES-LMC.

Types of concrete	Latex (%)	Coulombs	Air content (%)	Spacing factor (μm)	Curing time (days)
VEC	0	710	3.56	534.4	28
VES-LMC	15	127	2.52	274.5	

on the contrary due to the drastic increase in the number of microscopic entrained air void below 100 μm in diameter. Additionally, its permeability test revealed its impermeable property as evidenced by the measured coulombs in 100's despite the low spacing factor. Through these experimental results, it was found that the total air content did not exert considerable influence on VES-LMC after its hardening due to the use of anti-foamer and that the addition of latex was more influential on the properties of VES-LMC on the contrary.

4) The result of analyzing the change in air void structure inside latex-modified concrete by various types of content revealed that it did not vary greatly regardless of the mixing or no-mixing of latex and anti-foamer. Particularly, the addition of latex resulted in better entraining of microscopic air void and a low spacing factor below 300 μm. Nevertheless, the relationship between this air void structure and permeability was found to be unsubstantial. In other words, the permeability of latex-modified concrete is influenced directly by the film membrane of the latex polymer and is not affected so greatly by the change in the air void structure inside the concrete.

The relationship between the change in air void structure and permeability with the mixing of latex into the concrete was found to be inconsiderable regardless of the type of the cement based on the above conclusions. Additionally, the evaluation of super-microscopic (below one micro-meter, μm, in diameter) air void structure and its relationship with the mix ratio of latex should be carried out in the future so as to accomplish a more comprehensive analysis and evaluation of this research subject.

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