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Long-Term Durability of Roller-Compacted Concrete Pavement

Jun Hee Lee, Young Kyu Kim, Seong Jae Hong, Chamroeun Chhorn, Seung Woo Lee

***Abstract*—**Roller-compacted concrete pavement (RCCP), an environmental friendly pavement of which load carry capacity benefitted from both hydration and aggregate interlock from roller compacting, demonstrated a superb structural performance for a relatively small amount of water and cement content. Even though an excellent structural performance can be secured, it is required to investigate roller-compacted concrete (RCC) under environmental loading and its long-term durability under critical conditions. In order to secure long-term durability, an appropriate internal air-void structure is required for this concrete. In this study, a method for improving the long-term durability of RCCP is suggested by analyzing the internal air-void structure and corresponding durability of RCC. The method of improving the long-term durability involves measurements of air content, air voids, and air-spacing factors in RCC that experiences changes in terms of type of air-entraining agent and its usage amount. This test is conducted according to the testing criteria in ASTM C 457, 672, and KS F 2456. It was found that the freezing-thawing and scaling resistances of RCC without any chemical admixture was quite low. Interestingly, an improvement of freezing-thawing and scaling resistances was observed for RCC with appropriate the air entraining (AE) agent content; Relative dynamic elastic modulus was found to be more than 80% for those mixtures. In RCC with AE agent mixtures, large amount of air was distributed within a range of 2% to 3%, and an air void spacing factor ranging between 200 and 300 μm (close to 250 μm, recommended by PCA) was secured. The long-term durability of RCC has a direct relationship with air-void spacing factor, and thus it can only be secured by ensuring the air void spacing factor through the inclusion of the AE in the mixture.

***Keywords*—**RCCP, durability, air spacing factor, surface scaling resistance test, freezing and thawing resistance test.

I. Introduction

In modern society around the world, eco-friendly properties in all industry is emerging as a top priority, due to the acceleration of global warming caused by the augmentation of carbon dioxide concentrations into the atmosphere. Cement, a binder in concrete pavement, is continuously being used due to its outstanding durability and economic efficiency, which is known to emit carbon dioxide of approximately 870 kg per ton [10]. RCCP is introduced to pavement construction because it can achieve eco-friendliness and economic efficiency by reducing CO_2 through the use of a relatively low quantity of cement, while it secures excellent capability, and also ensures quick and simple construction procedure using asphalt construction equipment [13].

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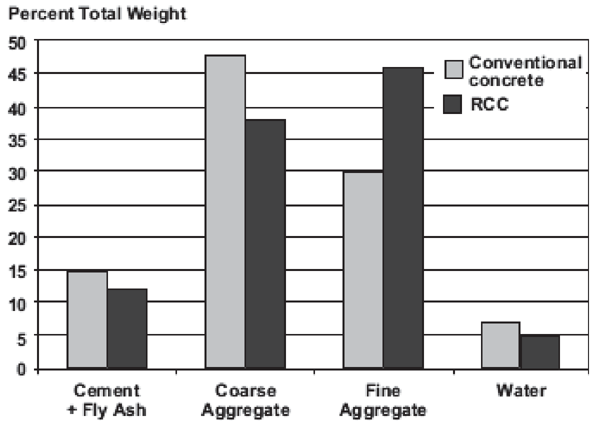

Fig. 1 Typical Material Comparisons of Conventional Concrete and RCC [7]

RCC for pavement has low cement content. This eco-friendly construction method can reduce carbon dioxide productivity and is very economical. Its material characteristics are similar to existing cement concrete pavement with different proportioning (Fig. 1). A study of the basic properties of RCCP for bicycles was conducted by [12]. The optimum mixing conditions require strength of not less than 21 MPa through variety of strength experiment based on formulation conditions and environmental load resistance evaluation was performed using the derived formulation condition. It was confirmed that the small bubbles which are distributed enough through compacting and dense form factor ensures relative elastic coefficient higher than 80% even though it has low amounts of air between 1.8% and 2.5% and excellent resistance to freezing-thawing. In the recent study by [13], the characteristics of aggregate size's impact on RCC for road pavement and aggregate gradation band was conducted using coarse 19 mm aggregate and fine aggregate. It was confirmed that the small particle portion has negligible impact on consistency, dry unit weight, strength of the RCCP, and thus, even if the particle passing through #60 sieve is excluded, excellent quality can still be secured. The long-term durability affected by the environmental load in previous studies is solely for bicycle roads and thus it is required to study the long-term durability of RCC for higher traffic volume roads. In conventional cement concrete, a proper amount of pores can be formed by entrained air and trapped air. However, the study of [6] suggested that the pore structure inside RCC can form a number of irregular pore shapes during the compaction

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process due to compacting and can secure excellent durability with a minimum of 1.5% of air pore and of maximum of 250 μm of air spacing factor. The purpose of this study is to confirm the change of air void and air spacing factor according to the mixing of the compound in the compacted concrete pavement and propose a remedy for long term durability by analyzing the correlation between freezing-thawing resistance, scaling resistance and inner pore structure.

II. Characteristics of Pore of the RCC

In order to improve the durability of concrete affected by frost, inner air pore plays a very important role. The pore can be classified into entrained pore and trapped pore by using AE agent. The pore performs a role of passage for penetrated water and prevents the occurrence of cracks inside and outside, as the resistance to frost increases due to the effect of relieving swelling pressure caused by the change of volume during frost.

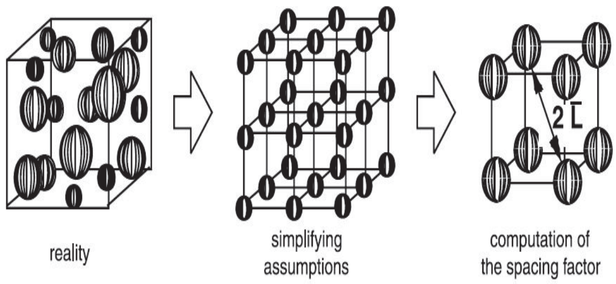

Fig. 2 Concept of Air-Spacing Factor [5]

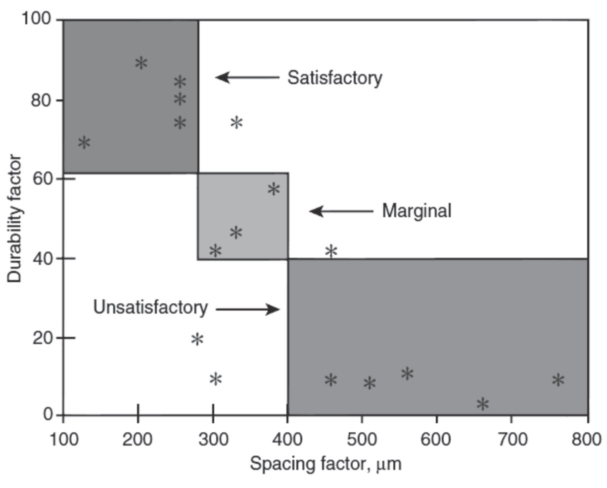

Fig. 3 Durability Factor versus the Air-Spacing Factor [6]

Air-Spacing Factor refers to the value obtained by dividing the distance between two pores located opposite to a cube, as locating the pore of average size in a cube and is used as a basis for evaluating the distance between the distribution extent and the space between pores of internal pores. Fig. 2 illustrates the concept of Air-Spacing Factor [11]. According to the study of [6], it is a characteristic of a number of irregular shapes of pores formed during the compression process by compaction in the case of RCC mixture. As the 1.5% minimum air pore is obtained, it is suggested that an air spacing factor of max. 250 μm would secure excellent durability, as shown in Fig. 3. However, since the dispersion and leakage of the inner air pore occurs due to compaction process in case of RCC, it is estimated that the fluctuation range of the air spacing factor would be large.

III. Experiment Condition

Six cases of RCC mixture are investigated in this study, as shown in Table I. Mixture proportioning for the reference RCC and PCC is given in Table II. PNS (Poly Naphtalene Sulfonate), which is high-performance water reducing admixture of naphthalene type, was used in order to secure workability and construction time. Since the slump of the mixture is 0 cm, workability and potential construction time was evaluated through measuring of Vebe Time in accordance with ASTM C 1170/1170M [4] and the range of appropriate Vebe was selected to be 30 second to 75 seconds in this study, with consideration of the 30 seconds to 40 seconds range suggested in ACI 325.10R-25 and 50 seconds to 75 seconds range suggested in the study of [8]. Table III shows the results of measuring Vebe Time for each elapsed time. At 2 hours after production of the first mixture, measured Vebe time satisfied the above selected range and it was confirmed that about 2 hours of construction time from mixing to compaction can be secured. In addition, the mixture with general AE and high-performance AE entrained the fine air bubbles inside concrete and promoted durability.

In order to simulate the process of the on-site roller compaction process indoors, the compaction in each layer was performed through the production of a Vibrating Hammer and compacting plate for each shape of mold as shown in Fig. 4. The time mortar rose to the border of the compaction plate is considered to be appropriate compaction time and the specimen is manufactured in compaction of a total of three layers.

TABLE I
Experimental Condition for RCCP

Type of mixture	Admixture ratio (%, wt. of Cement)		
	PNS	AE agent – 1 (Normal-Performance)	AE agent – 2 (High-Performance)
Ref	-	-	-
PNS	0.3	-	-
N-0.05	0.1	0.05	-
N-0.1	0.1	0.1	-
H-0.05	0.1	-	0.05
H-0.1	0.1	-	0.1

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TABLE II
MIXTURE PROPORTION

RCC											
Gmax (mm)	Slump (mm)	Air (%)	W/C (%)	S/a (%)	Unit Weight(kg/m^3)				Admixture: Notes of Table II		
					W	C	S	G	PNS	AE-1	AE-2
19	1	2(±1)	45	53	147	280	1285	864	-	-	-
PCC											
Gmax (mm)	Slump (mm)	Air (%)	W/C (%)	S/a (%)	Unit Weight(kg/m^3)				Admixture		
					W	C	S	G	AE Agent		
25	40	5~7	45	47	166	370	863	1,001	C × 0.3% Range		

TABLE III
RESULTS OF VEBE TEST

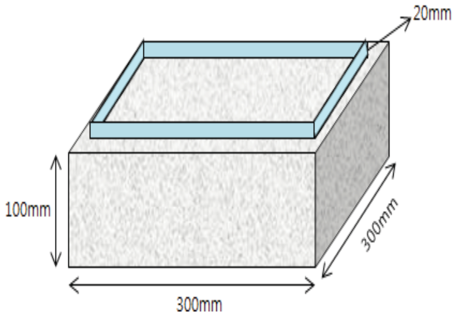
Elapsed time	Vebe Time(s)	
	RCCP(Normal)	RCCP + PNS
0 min	50	20
30 min	70	40
1 hr	96	48
2 hr	95	43
3 hr	>120	75

IV. FREEZING-THAWING RESISTANCE AND SCALING TEST

Deterioration of concrete due to frost in the winter reduces its durability by range of cracking and scaling off. The mechanism of deterioration is classified by 'hydraulic pressure theory' which is based on volume expansion by freezing of unfrozen water 'hydrostatic pressure theory', 'osmotic pressure' and 'aggregate expansion theory' caused by water freezing inside the aggregate. In this study, the method of thawing water after freezing in the air (B method) in accordance with KS F 2456[1] was tested in order to confirm the performance and durability of RCC.

Fig. 4 Freezing-Thawing Resistance Measurement Equipment

Scaling is the phenomenon that freezing-thawing, delamination and exposure of aggregate occurs by deterioration of the concrete surface caused by chemical action of the deicing material and salt sprayed on the road. In this experiment, the test specimens of a square of 100 × 300 × 300 mm in size were produced as shown in Fig. 5 (a). An acrylic plate of 20 mm height was installed to distribute evenly test solution in specific level. The test solution, calcium chloride of 4g per 100ml of distilled water, was placed on the specimen and the test was conducted within cycles basis with 1 cycle consisted of freezing for 17 hours and thawing for seven hours.



(a) Specimens model

(b) Proceed in accordance with the specimen type

Fig. 5 Scaling Test Appearance in Progress

To evaluate the surface condition of the testing specimen, the resistance to Mass of scaled off particles was checked visually, as referring to Table IV at 5, 10, 15, 25, 50 cycles and the weight loss of the specimen was measured through measuring scaling off.

TABLE IV
RATINGS OF SURFACE CONDITION ACCORDING TO THE VISUAL OBSERVATION (ASTM C 672[2])

Division	Surface Condition
0	no scaling
1	very slight scaling (3mm depth max no coarse aggregate visible)
2	slight to moderate scaling
3	moderate scaling (some coarse aggregate visible)
4	moderate to severe scaling
5	severe scaling (coarse aggregate visible over entire surface)

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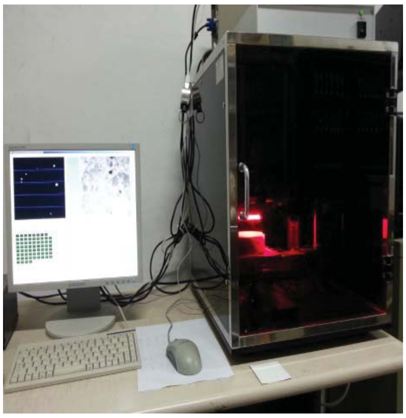
(a) The test specimen

(b) Surface Polishing



(c) Experimental appearance

Fig. 6 Experimental Procedure

V. Air Void and Air Spacing Factor Test

The image analysis experiments were conducted based on ASTM C 457[3] to measure the air void and air spacing factor in RCC. The purpose of this test method is to calculate the necessary parameters through actual checking the size and number of pores and which appears on surface of concrete magnified by the microscope and Linear Traverse was used for image analysis experiments. The specimen was checked on this device and it can be moved vertically and horizontally under a microscope and is measured along the cross line of a microscope in as many times as the number of horizontal lines dispersed on the entire surface [9]. For the test, a coring specimen of 100 mm diameter was cut off to be used and the specimen was then grinded by SiC powder, starting with the No.60 grinder through No. 100, 200, 320, 420, and finally the No. 600 grinder. After finishing the grinding operation, the experiment was conducted once the surface was cleaned thoroughly using strong water pressure in order to remove the exterior mass which invaded the pores of the specimen surface.

VI. Freeze-Thaw Resistance and Scaling Test Results

Fig. 7 shows the results of measured relative elastic modulus for Ref and PNS RCC, and PCC. PCC was found to maintain its durability after decreasing about 13% of relative elastic modulus after the first measurement of relative elastic modulus.

RCC without any admixture seemed to have good durability until 200 cycles, at which the relative elastic modulus starts to rapidly lower down and the specimen was destroyed at 270 cycles. For the RCC with PNS, early destruction was observed. As a result, RCC in which AE was not conducted was found to be vulnerable to freezing-thawing than normal PCC.

Fig. 8 shows the value of the relative elastic modulus of the specimen in which AE was conducted by adjusting the mixing ratio of general and high performance AE agents in addition to PNS as the second experiment. At the 300th cycle, the end of the experiment, the trend showed a similar reduction in relative elastic modulus for each case. However, their relative elastic modulus was found to be over 80%, which are the criteria of durability in road construction specification. Thus, AE through AE agent can be used to promote an anti-frost nature of RCC.

The result of the analysis based on the visual evaluation of ASTM C 672 on the surface of the specimen where deterioration occurred due to deicing agent is given in Table V below.

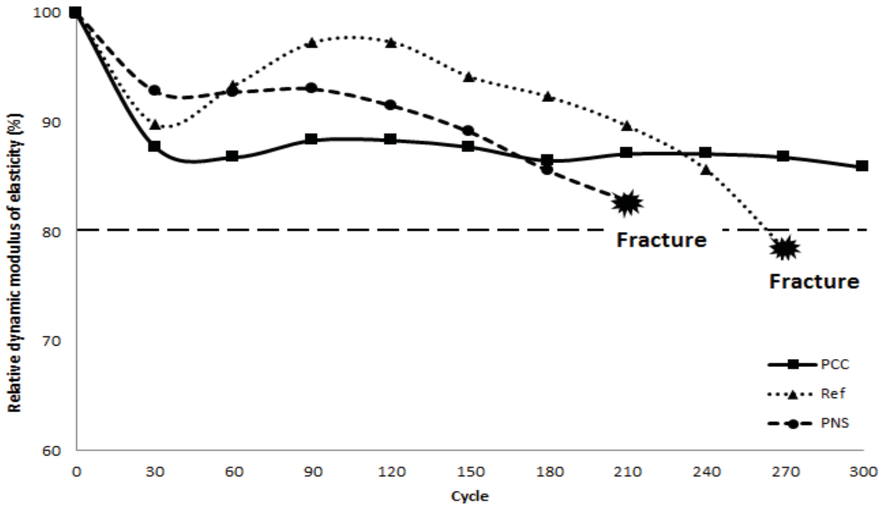


Fig. 7 Relative Dynamic Modulus of Elasticity according to the Freezing-Thawing Test (Non-AE)

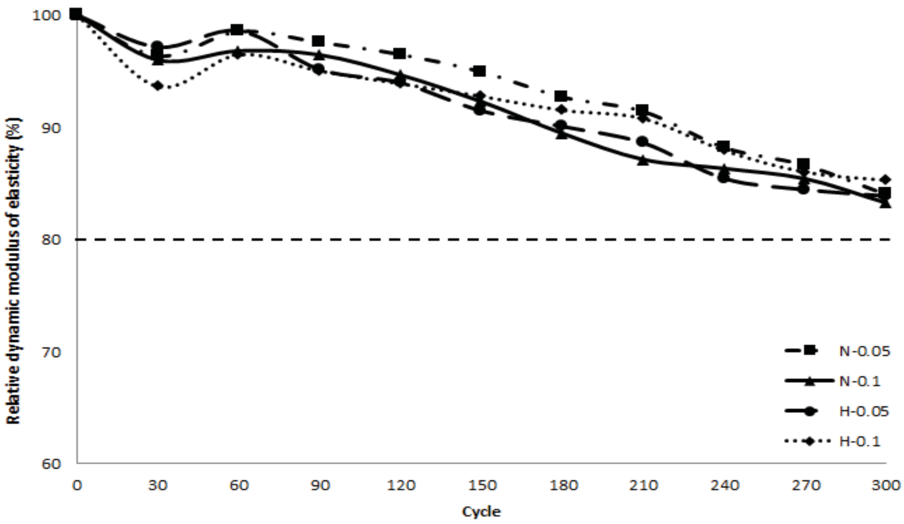


Fig. 8 Relative Dynamic Modulus of Elasticity of According to the Freezing-Thawing Test (AE)

RCC without AE agent was found to be 'Moderate to severe scaling' as deterioration occurred on a large area of the surface and exposure of coarse aggregate by visual checking. However, in the case of RCC with AE agent, it showed some difference depending on the usage amount of this agent. The specimen of RCC with 0.1 % AE agent was found to be 'Very slight scaling' which indicated the improvement of scaling resistance.

Fig. 9 illustrates the weight loss of each specimen based on the amount of scaling off measured at cycle of 5, 10, 15, 25 and 50 during the scaling test. In the case of RCC without AE agent, high weight loss rate of 0.2% or more was shown, while it was confirmed that a very small amount of weight loss occurred regardless of its performance in RCC with the appropriate amount of AE agent. Therefore, scaling resistance proves to be improved only when a sufficient amount of AE agent is used.

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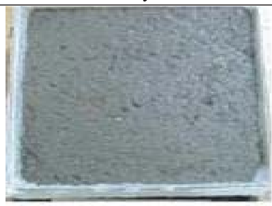
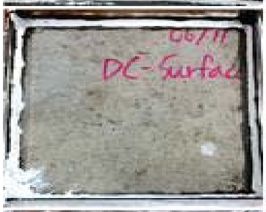
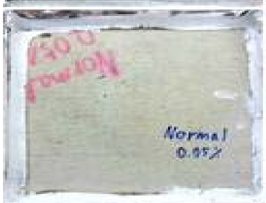
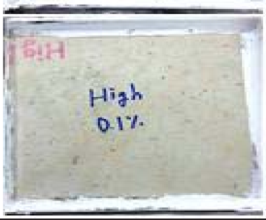
TABLE V
CHANGE OF SURFACE CONDITION DUE TO SCALING RESISTANCE

	Surface condition			
	0Cycle	25Cycle	50Cycle	After 50 Cycle
PCC				No scaling(0)
RCCP (Ref)				Moderate to severe scaling (4)
RCCP+PNS				Moderate to severe scaling (4)
RCCP+PNS+ AE-1 (0.05%)				slight to moderate scaling (2)
RCCP+PNS+ AE-1 (0.1%)				Very slight scaling (1)
RCCP+PNS+ AE-2 (0.05%)				slight to moderate scaling (2)
RCCP+PNS+ AE-2 (0.1%)				Very slight scaling (1)

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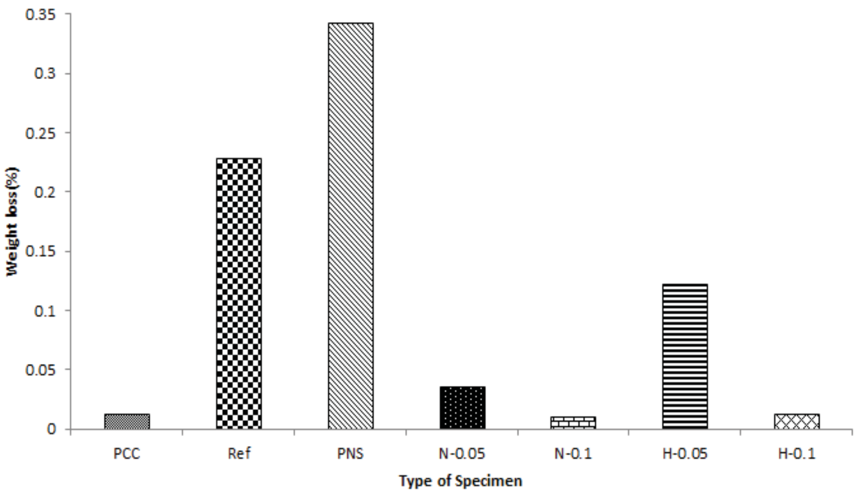

Fig. 9 Weight Reduction Rate after Surface Resistance Test of 50cycles

VII. Result of Measuring Air Void and Air Spacing Factor

Fig. 10 shows the correlation between air void and air spacing factor. The air void and air spacing factor was measured twice per type of specimen produced. In the case of the Ref RCC, the measurement result was obtained from coring the specimens of two sites which was added and shown in the graph. In the case of RCC without AE agent, the range of air void was found between 1% and 2%, and the air spacing factor was measured to be between 320 μm and 450 μm. In this case, air void approached the lower limit of 1.5% suggested in previous study, but the air spacing factor was much higher than the suggested figure, 250 μm. On the contrary, in the case of RCC with AE agent, the distribution was concentrated between 2% and 3% due to the effect of AE and it was confirmed that air void of 1% higher than before and dense air spacing was formed by securing an air spacing factor ranging from 200 μm to 300 μm.

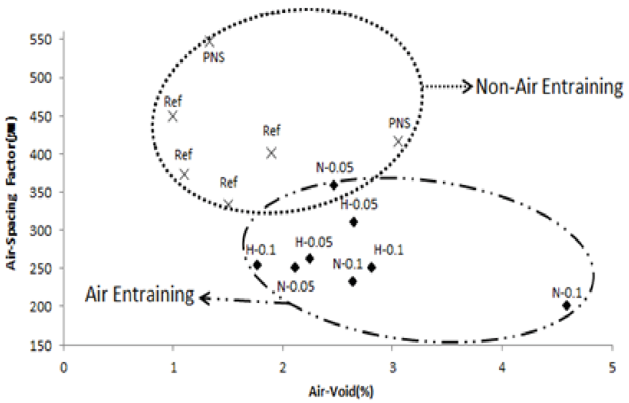

Fig. 10 Relationship between Air-Void and Air-Spacing Factor

VIII. Correlation of Long-Term Durability and Air Spacing Factor

Fig. 11 shows the correlation between long-term durability factor (DF) and air spacing factor. The excellence durability in each case of RCC that has an air spacing factor ranging between 200 μm and 300 μm, confirmed the maximum 250 μm air spacing factor by [6].

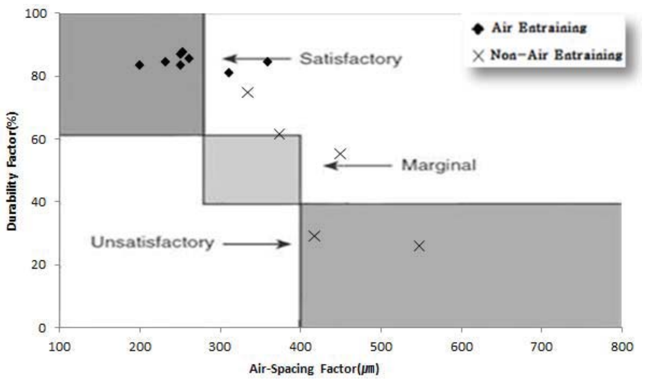

Fig. 11 Correlation between Durability Factor and Air-Spacing Factor

The rapid reduction of the durability factor was caused by the increase of the air spacing factor. Long term durability of RCC is considered to have a close relationship with air spacing factor rather than air void does. From this study, air void of 2% to 3 % and an air spacing factor of about 200 μm to 300μm is recommended for achieving RCC with high durability.

IX. Conclusion

In this study, durability test and measurement of air void and air spacing factor of RCC for pavement was performed. From this research, an improvement method by analyzing the correlation of long-term durability and air spacing factor and its major conclusion is given as follows:

- In RCC without AE agent, destruction of the specimen occurred early and it was found to be more vulnerable to freezing-thawing than regular PCC. For RCC with AE agent, the similar trend of relative elastic modulus reduction was observed until the experiment is finished, but its final relative elastic modulus was found to be over

80% which exceeded the criteria of durability in road construction specification. Therefore, AE agent is necessary in RCC in order to improve its resistance to frost.

- In RCC, serious weight loss and surface degradation occurred, but very small amounts of scaling off and an excellent surface condition were maintained in the mixture with the proper amount of AE agent. Therefore, it is necessary to use the proper amount of AE agent in order to improve resistance to scaling off of this concrete.
- In case of RCC without AE agent, air void was found between 1% and 2 % and the air spacing factor was measured to be in the range of 320 μm to 450μm, while in the case of RCC with AE agent, air void was found between 2% and 3% and air spacing factor was measured to be in the range of about 200 μm to 300 μm, as it formed denser air spacing than before.
- The result of analyzing the durability factor (DF) and air spacing factor shows that the long term durability of RCCP has a close relationship with air spacing factor and air spacing factor should be secure between 200 μm and 300 μm.

Acknowledgment

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References

[1] KS F 2456, Standard test method for resistance of concrete to rapid freezing and thawing.
[2] ASTM C672, Standard Test Method for Scaling Resistance of Concrete Surfaces Exposed to Deicing Chemicals.
[3] ASTM C457, Standard Test Method for Microscopical Determination of Parameters of the Air-Void System in Hardened Concrete.
[4] ASTM C1170, Standard Test Method for Determining Consistency and Density of Roller-Compacted Concrete Using a Vibrating Table.
[5] Richard Pleau, Michel Pigeon, Jean-Luc Laurencot, 2001, Some Findings of the Usefulness of Image Analysis for Determining the Characteristics of Air-Void System on hardened Concrete, Cement & Concrete Composites 23, pp. 237-246.
[6] Luhr, D. R., 2006, Frost Durability of Roller-Compacted Concrete Pavements, Portland Cement Association.
[7] Dale Harrington et al., 2010, Guide for Roller Compacted Concrete Pavements, National CP Tech Center.
[8] ACI 325.10R-25, Report on Roller Compacted Concrete pavements. Farshid Vahedifard., Mahmoud Nili., Christopher L. Meehan., 2010, Assessing the effects of supplementary cementitious materials on the performance of low-cement roller compacted concrete pavement, Construction and Building Materials, Vol. 24, No. 12, pp. 2528~2535.
[9] Yun, K. K., Jeong, W. K., Jun, I. K., and Lee, B. H., 2004, Analysis of Air Voids System Using Image Analysis Technique in Hardened Concrete, Journal of the Korean Concrete Institute, Vol. 16, No. 6. pp. 740~750.
[10] Han, H. S., and Jin, Y. M., 2009, The Future of Concrete Admixture Industry for Low Carbon, Green Growth, Journal of the Korean Concrete Institute, Vol. 21, No. 4, pp. 41~43.
[11] Hwang, H. J., and Kim, J. G., 2010, Evaluation of Chloride Attack Resistibility of Concrete Damaged Due to Freezing-Thawing, Master's Thesis, Dong-Eui University.
[12] Lee, C. H., Kim, Y. K., Kang, J. G., Park, C. W., and Lee, S. W., 2011, A Study on Construction Methods of Roller Compacted Concrete Pavement for Bike Roads, Journal of the Korean Society of Road Engineers, Vol. 13, No. 2 pp. 103~114.
[13] Song, S. H., and Lee, S. W., 2015, A Study on the Gradation Effect of the Property of Roller Compacted Concrete Pavement, Journal of the Korean Society of Road Engineers, Vol. 17, No. 3 pp. 49~58.

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