FREEZE-THAW DURABILITY OF SB LATEX-MODIFIED CONCRETES WITH CEMENT TYPES

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ABSTACT

This study focused on the investigation of durability of latex modified concrete with cement types in the points of freeze-thaw and surface scaling resistances. The main experimental variables were cement type (ordinary Portland cement and rapid-setting cement) and latex content (0%, 5%, 10%, 15% and 20%). The results were as follows:

From the freeze-thaw resistance test, the relative dynamic modulus of elasticity of LMC maintained above 90% after 300 freeze-thaw cycles at concrete containing more than 5% latex. The difference of void and permeability system between OPC and LMC was described. Within the range of this study, both of RSC and RSLMC seemed to have enough freeze-thaw resistance. This comparative study, however, indicated that SB latex significantly improved the freeze-thaw resistance in terms of relative dynamic modulus and durability factor.

In the deicer salt scaling test using weight loss and visual rating, the damage to surface scaling decreased as latex content increased. The results of deicer salt scaling test at very early-age also indicated the importance of curing at early-age: The concrete repairs, which would be exposed to very cold weather at early-age, would have severe scaled-off surfaces regardless of its concrete mixtures.

Keywords: LMC(latex modified concrete), permeability, freeze-thaw resistance, scaling resistance

INTRODUCTION

Latex modification of concrete provides the material with higher flexural strength, as well as high bond strength and reduced water permeability[1]. Improvement of workability through latex modification is another factor contributing to the flexural strength in the latex modified concrete. One of the most advantages of the latex-modified concrete (LMC) could be the similar contraction and expansion behaviour to normal concrete substrate, which enable to ensure long-term performance.

Common applications of latex modified concrete are overlays of bridge deck, parking structure and industrial floors. Since the inception of polymer-modified Portland cement for bridge deck repair in 1957, thousands of projects have been completed using styrene-butadiene latex in concrete for overlay in the United States[2]. Although its improved physical properties and workability make it the most widely used material at bridge deck overlay, the LMC with ordinary Portland cement has a limit in application at newly constructed job site due to its long required curing. Thus, a rapid-setting latex modified concrete was developed in order to overcome this limit still holding all advantages of LMC[3, 4].

In cold climates where the temperature fluctuates above and below freezing, freeze-thaw damage of concrete, seen as cracking and scaling of the surface, occurs when water freezes in the concrete pores. When de-icing salts are used, the deterioration becomes more severe. This study focused on the durability of latex modified concrete with ordinary Portland cement and rapid-setting cement in the points of freeze-thaw and surface scaling resistances.

EXPERIMENTAL PROGRAMS

The main experimental variables were cement types and latex contents in order to investigate the freeze-thaw and surface scaling resistances of latex modified concrete in cold climate. The cement types considered were ordinary Portland cement and rapid-setting cement, and the latex content rates (latex solid/cement as %) were 0%, 5%, 10%, 15% and 20% at a fixed cement content of 660 lb/yd^3 and a targeted slump of 8±0.5 inch. The checked properties of fresh concrete were slump, air content and setting time, and the hardened were compressive and flexural strength developments. For durability properties the freeze-thaw and deicer salt surface scaling resistance tests were performed according to ASTM C 666 and ASTM C 672, respectively. This paper describes only a part of strength development test and durability test results.

MATERIALS

Cements

For applications at emergency repairs of concrete pavements and structures, hydraulic cements are needed that are not only rapid-hardening but also rapid-setting. Rapid-setting cement, which derives its rapid strength development properties from the formation of large amounts of ettringite during the early hydration period, was used. The cement is very fast setting, thus it is retarded by addition of citric acid in order to ensure working time. A rapid-setting cement was selected after a series of pilot tests which included nine rapid-setting cements produced in Korea[4]. Table 1 compares the chemical composition and physical properties between ordinary Portland cement and rapid-setting cement.

Latex

Latexes are colloidal dispersions of small spherical organic polymer particles in water, and they are generally milky fluids that are white to off-white in color. The particles are held in suspension in water by coating their surface with a surfactant[5]. The latex used was a styrene-butadiene type produced by Dow Reichhold Specialty Latex LLC. The detail physical properties are given in Table 2.

Aggregates

The maximum size of coarse aggregate was 0.5 inch considering the thickness of bridge deck overlay. The coarse aggregate was crushed limestone and the fine aggregate was natural sand. To keep the grade satisfying the given Korean specifications (KS F), both fine and coarse aggregates were verified in laboratory test. The specific gravities of coarse aggregate and fine aggregates were 2.57 and 2.6, respectively.

CONCRETE MIXING AND CURING

The main experimental variables were latex contents varying from 0% to 20% and water-cement ratio varying from 36% to 40%. The latex content varied 0%, 5%, 10%, 15% and 20% at the fixed cement content of 660 lb/yd^3 and a targeted slump of 8±0.5 inch. The water-cement ratios were 36%, 38% and 40% at a fixed latex-cement ratio. Water content was reduced in latex-modified concrete in order to produce the concrete mixes of the targeted slump. The concrete mix proportions for ordinary Portland cement concrete (OPC), rapid-setting cement concrete (RSC), latex-modified concrete (LMC), and rapid-setting latex-modified concrete (RSLMC) are shown in Table 3.

Table 1. Chemical Composition of Cements

Cement Type	Chemical Composition (%)						Blaine (cm^2/g)	Specific Gravity
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3		
Ordinary Portland Cement	20.8	6.3	3.2	61.2	3.3	2.3	3,200	3.15
Rapid-setting Cement	10.2	16.7	1.3	50.8	1.4	15.5	5,400	2.90

Table 2. Physical Properties of Latex

Solid Content (%)	Butadiene Content (%)	Styrene Content (%)	pH	Average particle size	Surface charge	Specific Gravity	Minimum film forming temp (^{o}F)
48	34±1.5	66±1.5	9.5	1900 ˜ 2500Å	Nonionic	1.01	40

Table 3. Concrete Mix Proportion of OPC, RSC, LMC, and RSLMC

Concrete Type	W/C (%)	Fine/ Total Agg. (%)	L/C (%)	Mix Proportion (lb/yd^3)				
				Cement	Water	Fine aggregate	Coarse aggregate	Latex
OPC	35	34	0	678	237	1,052	2,049	0
	45	30	0	678	305	876	2,049	0
LMC	37	55	5	678	217	1,715	1,413	68
			10	678	183	1,667	1,374	136
			15	678	149	1,620	1,335	203
			20	678	115	1,571	1,296	272
RSC	49	58	0	661	323	1,654	1,239	0
RSLMC	45		5	661	154	1,654	1,232	69
	39		10	661	110	1,656	1,240	138
	33		15	661	65	1,667	1,249	206
	28		20	661	25	1,667	1,249	276

No standard methods were established for mixing of latex modified concrete with rapid-setting cement. Thus, the concrete mixing with latex followed to the previous study [1,4]. The mixing procedures with latex were as following: dry mixing for 30 seconds with coarse and fine aggregates; another dry mixing for 60 seconds after cement addition; and wet mixing for 90 seconds after latex and water pouring. The accepted curing procedure for RSLMC and LMC are 100% relative humidity for the first 24 hours followed by air curing at 50% of relative humidity until test[1].

TEST METHODS

Compressive and Flexural Strengths

The tests for hardened concrete included compressive strength using a cylinder of 4×8 in according to KS F 2405, flexural strength using beam specimens of 4×4×18 in according to KS F 2408, and split tension test using a cylinder of 4×4 in according to KS F 2423. These tests were selected in order to check the strength development for concrete mixtures, and finally in order to investigate the latex modification effect onto the concrete properties.

Freeze-Thaw Resistance Test

Freeze-thaw resistance test was performed according to ASTM C 666 (Resistance of Concrete to Rapid Freezing and Thawing, Procedure A). Both samples of LMC and RSLMC were wet curing for first 24 hours and air curing for another 27 days. The temperature at specimen center varied from 0 ^oF to 40 ^oF for 4 hours per cycle. Figure 1 shows the measured temperature at specimen center and test chamber. The dynamic modulus was calculated by measuring natural frequency at every 30 cycles. The test was continued until 300 cycles or until the dynamic modulus has reached 60% of its initial value, whichever occurred first. A durability factor (D.F.) could then be calculated as:

$$D.F.=P \times N/300 \quad \text{------------------------------------} \quad (1)$$

where, P is the percentage of the initial dynamic modulus after N cycles.

Deicer Salt Surface Scaling Resistance Test

Deicer salt scaling resistance test was performed according to ASTM C 672 (Scaling Resistance of Concrete Exposed to Deicing Chemical). The samples of LMC were wet cured for first 24 hours and air cured for another 27 days, while those of RSLMC were wet cured only 3 hours before scaling test for comparing and considering early-exposure to severe cold weather. The specimens were fabricated in a shape of rectangular by 8x10x4 in as shown in Figure 2. A rubber wall of 1 in high was mounted at the edges of specimen in order to maintain 4% calcium chloride solution. A solution of $CaCl_2$ was ponded on the surface of the specimen, which were then subjected to freezing- thawing cycles. 1 cycle of cooling and heating consisted of freezing at 0 ^oF for 16 to 18 hours and thawing at 73 ^oF in 45-55% RH for 6 to 8 hours. The specimens were weight measured and visual examined every 5 cycles in order to check weight loss and surface scaling rate, respectively. The visual rating of ASTM C 672 was adopted for assessing scaled surface as shown in Table 4.

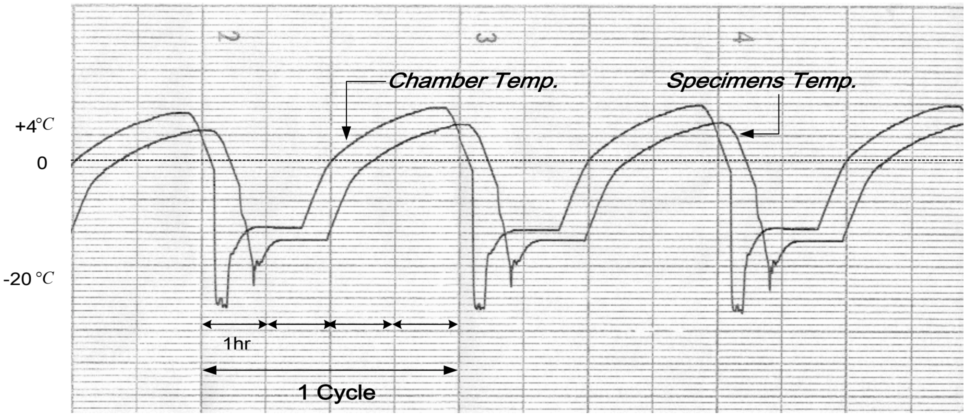


Fig. 1 Measured Temperature of Freeze-Thaw Test

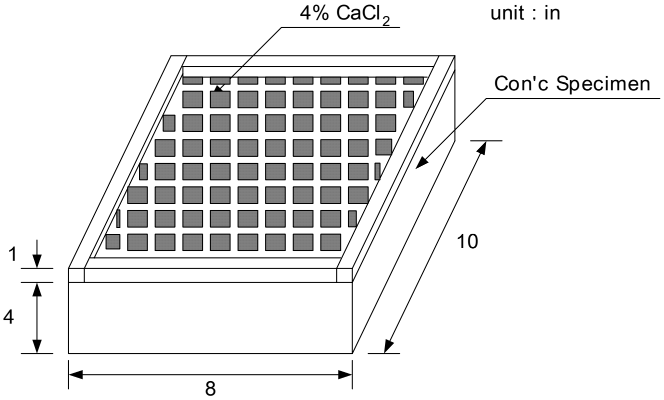


Fig. 2 Schematic of Specimen for Surface Scaling Test (unit : in)

Table 4. Criteria for Visual Rating of Surface Resistance (ASTM C 672)

Rating	Condition of surface
0	*No scaling*
1	Very light scaling (maximum depth of 3mm, 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)

STRENGTH TEST RESULTS AND DISCUSSIONS

Latex-Modified Concrete with Type I Cement

Compressive Strength

Table 5 compares the strength development of OPC and LMC with variation of water-cement ratio and latex content. The reported results are average of the three samples for each mix and each test. The standard variations were as small as the negligible. The compressive strength of LMC decreases as latex content increases. This decrease is mainly due to flexibility of latex component named by Butadiene. The compressive failure mechanism is affected by these polymer microfilms, and results in decrease in compressive strength. However, a significant reduction of water-cement ratio could be achieved by latex inclusion and this leads to make up the decreased compressive strength[8].

Table 5. Strength Development of OPC and LMC

	W/C (%)	Latex (%)	Compressive strength (psi)	Flexural strength (psi)
OPC	35	0	5,700	785
	45	0	3,340	614
LMC	37	5	5,285	685
		10	5,185	800
		15	5,042	885
		20	4,028	942

Flexural Strength

Increasing the amount of latex produces concrete with increased flexural strength compared to OPC. The flexural strength at 20% latex modified concrete is 942psi, 27% and 15% larger than at 5% latex and 10% latex modified concretes, respectively. These increases might be due to the latex microfilm between hydrated cement and aggregates. The increase in flexural strength can be attributed to the crack-arresting action of polymer in concrete, and also to the bonding they provide between the matrix and aggregates.

Rapid-Setting Latex-Modified Concrete

Compressive Strength

Table 6 shows the compressive and flexural strength developments of RSLMC with latex contents and antifoam contents. The compressive strength of RSLMC increases up to 4.8% of antifoam content but decreases at further antifoam inclusion. The strength development rate becomes smaller as curing age increases. The initial compressive strength at 3 hours decreases as latex content increase from 5% to 20%. Especially the initial compressive strength at 20% latex content is very low compared to the others. This may be due to the excessive dispersing particles that inhibit a cement hydration between cement particle and water at early age. This decrease, however, becomes smaller at longer curing ages.

Flexural Strength

The antifoam doesn’t affect to the initial and long-term flexural strength development of RSLMC except at 6.4% inclusion. The excessive usage of antifoam brings to reduction of flexural strength. The effect of latex content into flexural strength development at RSLMC is large enough. The flexural strength at 3 hours is 357psi and 785psi at 0% latex and 15% latex content, respectively. The flexural strength criterion for opening to traffic in Korea, 640psi, is met after 3 hours at 15% latex and 20% latex content. The concrete has a higher flexural strength because the water-cement ratio is lower and because the plastic film produces higher bond strength between the plastic and aggregates.

Table 6. Strength Development of RSLMC with Curing Ages

Latex (%)	Antifoam (%)	w/c (%)	Compressive Strength(psi)				Flexural Strength (psi)			
			3 hrs	6 hrs	24 hrs	28 days	3 hrs	6 hrs	24 hrs	28 days
15	0	33	3,214	3,671	4,728	6,000	757	900	1,057	1,400
	1.6		3,371	4,842	5,557	6,828	785	957	1,100	1,642
	3.2		3,628	4,857	5,457	6,642	800	1,000	1,085	1,471
	4.8		3,671	4,842	5,657	6,914	757	985	1,085	1,514
	6.4		3,271	3,928	5,128	6,271	742	857	871	1,300
0	1.6	49	2,271	2,742	4,942	5,485	357	677	685	914
5		45	3,985	4,371	5,442	7,400	600	885	957	1,385
10		39	3,700	4,242	5,300	7,942	585	942	1,028	1,500
15		33	3,371	4,842	5,557	6,828	785	957	1,100	1,642
20		28	2,214	4,500	5,257	6,371	757	1,071	1,200	1,528

TEST RESULTS AND DISCUSSION OF FREEZE-THAW DURABILITY

Latex-Modified Concrete with Type I Cement

Freeze-Thaw Resistance

Figure 3 shows a relative dynamic modulus of elasticity for LMC. The relative dynamic modulus of all mixes should be less than 100% if the strength of concrete remained same or its initial measurement of natural frequency is right. However, some of these are larger than 100%, indicating that the initial measurement might be under estimated. The relative dynamic modulus of elasticity maintains above 90% after 300 freeze-thaw cycles at concrete containing more than 5% latex. The greater resistance to damage from freeze-thaw cycles might come from the improved bond strength between plastic and aggregates. The ordinary Portland cement concretes require appropriate air content in order to acquire a freeze-thaw resistance.

However, the quantity of air in latex modified concrete does not significantly affect chloride permeability and the air void system of LMC is significantly different from that of conventional concrete[6]. The difference of void and permeability system between OPC and LMC could be described as shown in Figure 4. The void in OPC allows water to be penetrated inside of voids, while void in LMC doesn't allow water because the void itself is impermeable due to latex film at void surface.

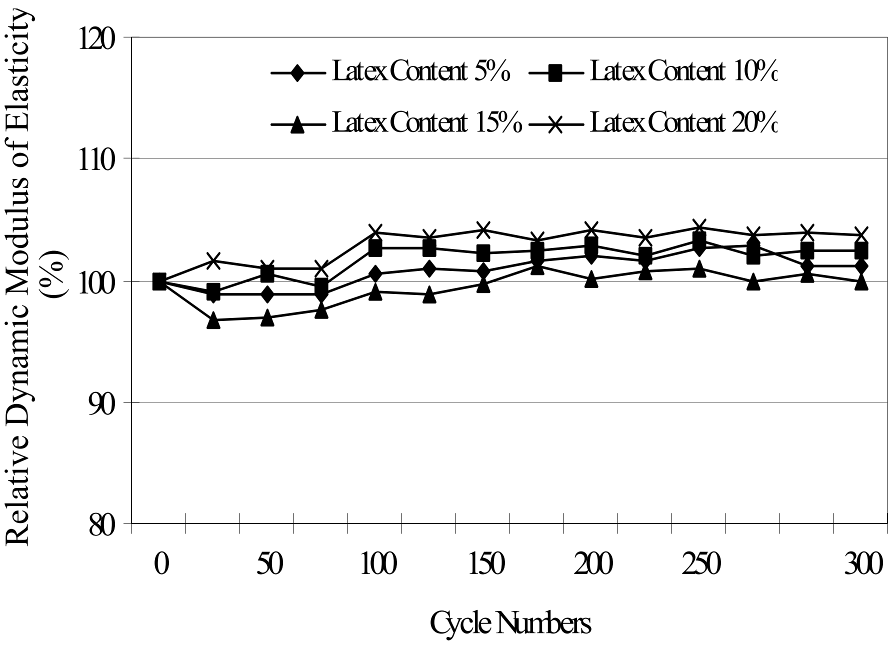


Fig. 3 Relative Dynamic Modulus of Elasticity for LMC

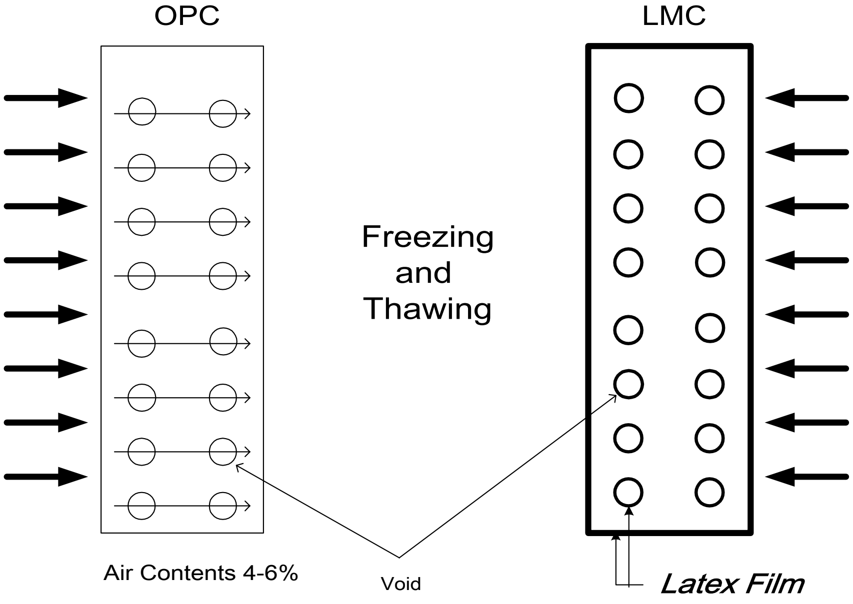


Fig. 4 Difference of Voids and Permeability for OPC and LMC

Surface Scaling Resistance to Deicing Salt

Concrete may be damaged by repeated application of de-icing salts. Concrete that has suffered salt scaling becomes roughened and pitted due to spalling of small piece of mortars. Table 7 shows weight losses of OPC and LMC in the unit of g/m^2 that is common expression. The weight loss of latex-modified concrete having higher flexural strength indicates less loss, as expected. The orders of weight losses for OPC and LMC are quite different. Those of LMC are small as 1/140 to 1/30 times of OPC. The weight loss decreases as latex content increases at all cycles and steps as shown in Figure 5.

Table 8 shows the visual rating results of scaled-off surface after 50 cycles, indicating 4 or 5 rate for OPC while 0 rate for all latex modified mixes. From the results of weight loss and visual rating, it could be concluded that the resistance to damage against freezing and thawing are greatly improved by latex. No more chemical admixtures are required for this purpose.

Table 7. Weight Loss of LMC Due to Surface Scaling (Unit : g/m^2)

	W/C (%)	Latex (%)	Cycles									
			5	10	15	20	25	30	35	40	45	50
OPC	35	0	1.9	10.4	13.0	39.0	72.8	189.8	510.1	1,035.3	1,693.12	2,480.9
	45	0	15.6	54.6	72.8	135.2	327.6	611.0	1,087.3	1,673.9	2,357.7	3,150.7
LMC	37	5	0.0	0.0	6.4	10.0	13.3	14.5	16.7	19.1	21.2	22.5
		10	0.0	0.0	5.8	8.8	11.5	12.4	14.3	15.8	17.3	18.5
		15	0.0	0.0	3.2	4.2	6.3	7.2	8.2	10.2	11.7	13.3
		20	0.0	0.0	0.7	2.6	3.6	4.5	5.8	6.8	9.7	10.2

Table 8. Visual Rating Results of LMC after 50 Cycles

Concrete Type	W/C (%)	Latex Content (%)	Visual Rating
OPC	45	0	5
	35	0	4
LMC	37	5	0
		10	0
		15	0
		20	0

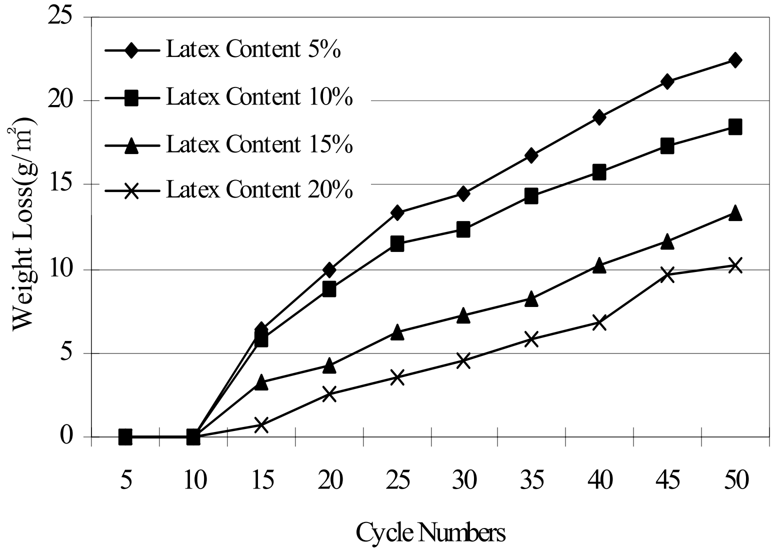


Fig. 5 Weight Loss of LMC with Latex Contents

Rapid-Setting Latex Modified Concrete

Freeze-Thaw Resistance

The variation of relative dynamic modulus of RSLMC with latex contents is shown at Figure 6. The relative dynamic modulus of elasticity of RSLMC maintains above 90% after 300 cycles, while those of rapid-setting cement concrete (RSC) dropped under 90% after 250 cycles. The durability factor of RSLMC with latex contents is shown at Figure 7. All durability factors of RSLMC are above 90%, while that of RSC is 86%. A durability factor less than 40 may be unsatisfactory, whereas above 60 it is likely to perform well [7]. Thus, all concretes within this study might satisfy in terms of durability factor.

Within the range of this study, both of RSC and RSLMC seemed to have enough freeze-thaw resistance because of their inherent high strength and latex action. This comparative study, however, indicated that SB latex improved significantly the freeze-thaw resistance in terms of relative dynamic modulus and durability factor.

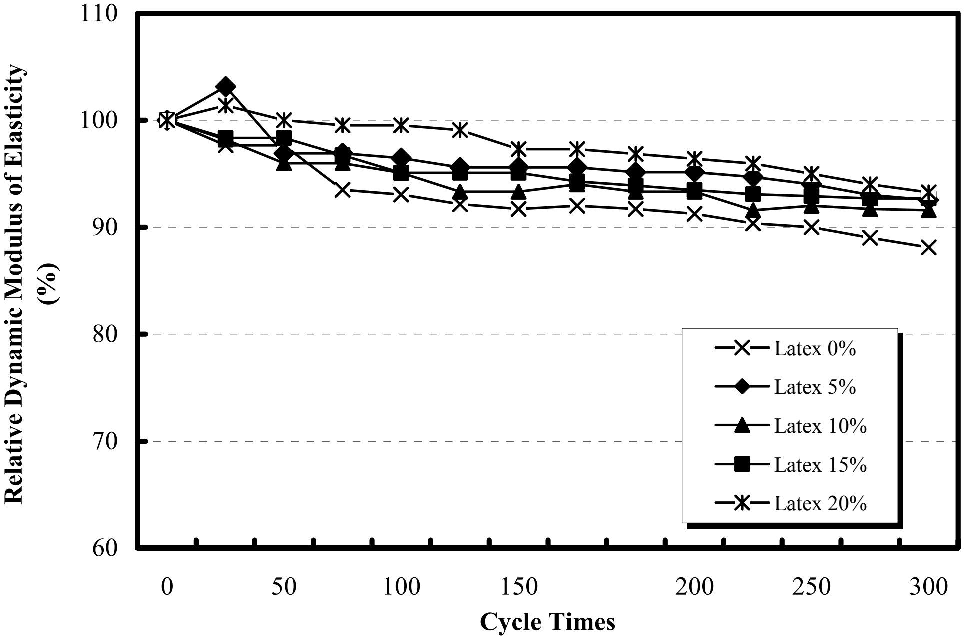


Fig. 6 Variation of Relative Dynamic Modulus of RSLMC

Surface Scaling Resistance to De-icing Salt at Very Early-Age

The visual rating of scaled surface with latex contents for RSLMC is shown in Table 9. The rapid-setting concrete is rated as 5 only after 5 cycles, while the rapid-setting concrete modified by 20% latex is rated as 2 after 30 cycles and still maintains as 4 after 50 cycles. The concrete modified by 15% latex is rated as 3 after 20 cycles, 4 after 30 cycles and 5 after 40 cycles. The damage to surface scaling decreases as latex content increase as shown in Figure 8. The weight loss of 20% latex modified concrete after 50 cycles is the smallest ($9g/m^2$), 9.7% of the non-modified. Figure 9 shows the photos of scaled surface with latex contents after 50 cycles.

Thus the problem of rapid-setting cement concrete that is vulnerable to chloride attack could be solved by containing latex in concrete. This would, also, result in the improvement of durability and greater resistance to damage from freezing and thawing cycles. These results would, also, indicate the importance of curing at early-age. The concrete repairs, which would be exposed to very cold weather at early-age, would have severe scaled-off surfaces regardless of its concrete mixtures.

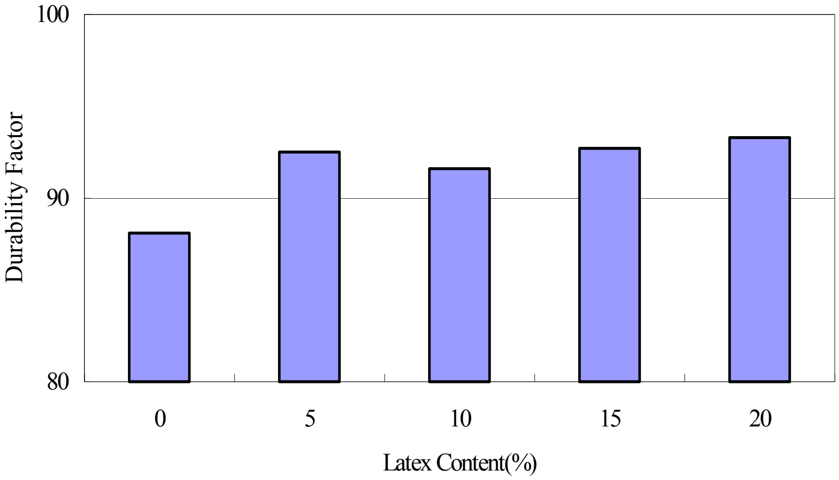


Fig. 7 Durability Factor of RSLMC

Table 9. Visual Rating of Scaled Surface with Latex Content for RSLMC

Latex Content (%)	Cycles					
	5	10	20	30	40	50
0%	5	5	5	5	5	5
5%	4	5	5	5	5	5
10%	3	3	4	5	5	5
15%	0	1	3	4	5	5
20%	0	0	2	2	3	4

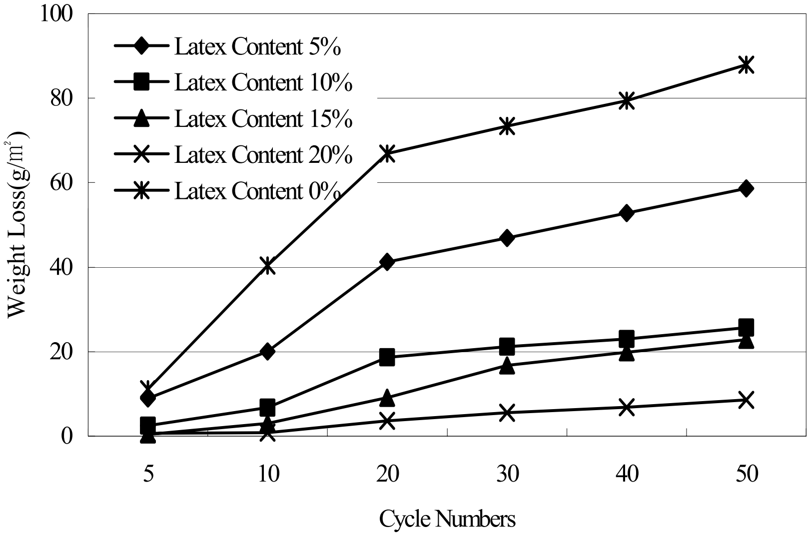
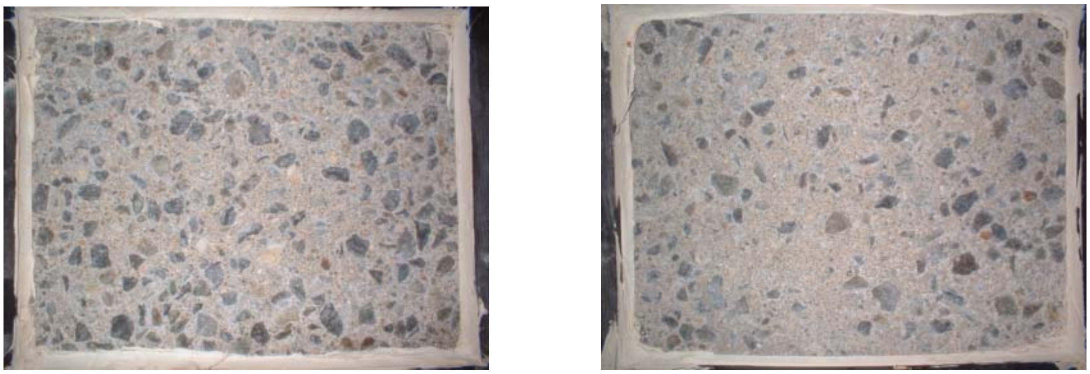
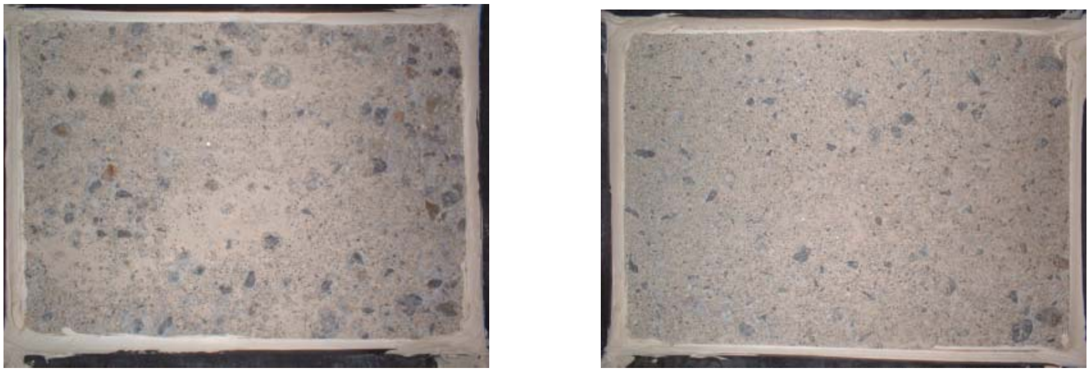


Fig. 8 Weight Loss of RSLMC with Latex Contents



(a) Latex Content 0% (b) Latex Content 5%



(c) Latex Content 10% (d) Latex Content 15%

(e) Latex Content 20%

Fig. 9 Scaled-off Surface of RSLMC after 10 Cycles

CONCLUSIONS

This study focused on the durability of latex modified concrete with ordinary Portland cement and rapid-setting cement using freeze-thaw and deicer salt scaling resistance tests. The main experimental variables were cement types (ordinary Portland cement and rapid-setting cement) and latex contents (0%, 5%, 10%, 15% and 20%). The results are as follow:

1. Flexural test result indicated the flexural strength of 20% latex modified concrete was 942psi, 27% and 15% larger than at 5% latex and 10% latex modified concretes, respectively. The effect of latex into flexural strength development at RSLMC was large enough. The flexural strength at 3 hours was 357psi and 785psi at 0% latex and 15% latex content, respectively. The flexural strength criterion for opening to traffic was met after 3 hours at 15% latex and 20% latex content.

2. The relative dynamic modulus of elasticity of LMC maintains above 90% after 300 freeze-thaw cycles at concrete containing more than 5% latex. The difference of void and permeability system between OPC and LMC was described. The void in OPC allows water to be penetrated into the inside, while void in LMC doesn't because void itself is impermeable due to latex film at void surface.

3. The relative dynamic modulus of elasticity of RSLMC maintained above 90% after 300 cycles, while those of rapid-setting cement concrete (RSC) dropped under 90% after 250 cycles. Within the range of this study, both of RSC and RSLMC seemed to have enough freeze-thaw resistance. This comparative study, however, indicated that SB latex significantly improved the freeze-thaw resistance in terms of relative dynamic modulus and durability factor.

4. In the deicer salt scaling test, the weight loss of latex-modified concrete having higher flexural strength indicates less loss, as expected. The visual rating results of scaled-off surface after 50 cycles were 4 or 5 rate for OPC while 0 rate for all latex modified mixes. From the results of weight loss and visual rating, it could be concluded that the resistance to damage against freezing and thawing are greatly improved by latex. No more chemical admixtures are required for this purpose.

5. The visual rating of scaled-off showed that the rapid-setting concrete is rated as 5 only after 5 cycles, while the rapid-setting concrete modified by 15% latex is rated as 3 after 20 cycles, 4 after 30 cycles and 5 after 40 cycles. The damage to surface scaling decreases as latex content increase. The results of deicer salt scaling test at very early-age also indicated the importance of curing at early-age: The concrete repairs, which would be exposed to very cold weather at early-age, would have severe scaled-off surfaces regardless of its concrete mixtures.

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