DEVELOPMENT OF SB LATEX MODIFIED-CONCRETE WITH RAPID-SETTING CEMENT FOR CONCRETE BRIDGE DECK OVERLAY

Kyong-Ku Yun, PhD, Assistant Professor at Kangwon National University in Korea and currently Exchange Professor over Slippery Rock Univ. of PA, Slippery Rock, PA16057
Dong-Ho Kim, PhD, Post Doctor, RRC at Kangwon National University, Chunchon, S.Korea
Chi-Moon Won, PhD, Assistant Professor, Dept. of Civil Engineering, Halla University, Wonju, S. Korea

ABSTRACT

SB latex modified- concrete with rapid-setting cement (RSLMC) was developed focusing on workability and strength development for early opening to the traffic after 3 hours of concrete placement, which could be used at repairing jobs of concrete bridge deck overlay. The developed RSLMC was evaluated in terms of mechanical properties and durability. The results were as follows:

Increasing the amount of latex, concrete displayed increased flexural strength, but slightly lower compressive strength. The permeability of RSLMC was very low indicating below 100 coulombs at 15% of latex contents. Within this study, both RSLMC and RSC exhibited good freeze-thaw performance, even though the latex-modified exhibited superior resistance. Rapid chloride permeability and freeze-thaw tests indicated that the developed concrete was good enough to protect the concrete bridge deck and to carry out cyclic freezing and thawing.

Keywords: SB Latex Modified Concrete, Rapid Setting Cement, Development, Durability

1 INTRODUCTION

A regulated-set cement has been used for rapid repair work, and possibly also for precast concrete. But, the regulated-set cement is vulnerable to sulfate attack because of the high content of calcium aluminate[1]. In certain situations, these problems can be solved by using materials that contain an organic polymer or resin (commercial polymer) instead of or in conjunction with Portland cement. This rapid-setting latex-modified concrete (RSLMC) may offer the advantages of high-early-strength, higher flexural strength, higher bond strength, improved durability, good resistance to corrosion, reduced water permeability and greater resistance to damage from freeze-thaw cycles[2,3,4].

The purpose of this study was to develop a latex-modified concrete with rapid-setting cement focusing on workability and strength development for early opening to the traffic, which could be used at repairing jobs of concrete bridge deck overlay. A series of experimental works were performed such as selecting and modifying rapid-setting cement, choosing antifoam, optimizing concrete mixture, optimizing retarder quantity, checking workability and strength development, and investigating durability. Finally, the developed RSLMC was evaluated in terms of mechanical properties and durability.

This paper presents only a part of development works concentrating on the effects of latex and antifoam on SB latex-modified concrete with rapid-setting cement.

2 EXPERIMENTAL PROGRAMS

2.1 EXPERIMENTAL PLAN

The main experimental variables were a latex content and antifoam quantity because these were one of the most important factors affecting to workability and strength development of RSLMC, which were verified from pilot tests. The latex contents were 0, 5, 10, 15, and 20%, and the antifoams were 0, 1.6, 3.2, and 6.4%. The tests included air content, initial slump and slump loss, initial and final setting, compressive and flexural strength development, rapid permeability of chloride ion, and freeze-thaw resistance.

2.2 MATERIALS

Rapid-Setting Cement

Rapid-setting cements could be grouped into three types; hauyne, $C_{12}A_7$, and alumina cement. The chemical compositions and physical properties of these rapid-setting cement types are shown in Table 1. Alumina cement type has $C_{11}A_7$-CaF_2 as a main ingredient, $C_{12}A_7$ cement type has $C_{12}A_7$ and CaSO4, and hauyne cement type has C-S-A. After basic experiments were carried out using these three types of rapid-setting cement in terms of workability and strength developments for RSLMC, a hauyne cement type was selected because early-age strength development, workability, and stability with latex were the best among them[1].

Latex and Antifoam

Latexes are a colloidal dispersions of small spherical organic polymer particles in water, and they are generally milky fluids that are white to off-white in color[4,5]. The particles are held in suspension in water by coating their surface with a surfactant. Styrene-butadiene latex manufactured by Dow Reichhold Specialty Latex LLC was used, which consists of 52% of water and 48% of solid. Antifoam used was silicon type manufactured and supplied in Korea. The physical properties of latex are shown in Table 2.

Aggregates

The coarse aggregate was crushed limestone, maximum particle size of 13mm (0.5in) considering a bridge overlay thickness; the fine aggregate was natural sand. Both are satisfying the Korean Specification (KS F). The physical and chemical properties of aggregates are given in Table 3.

Table 1. Chemical Composition and Physical Properties of Rapid-Setting Cement (unit : %)

	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3
Hauyne	10.2	16.7	1.3	50.8	1.4	15.5
$C_{12}A_7$	15.4	15.4	9.1	21	58.9	0.6
Alumina	13 ± 3	17.5 ± 3	3	50 ± 3	2.5	11 ± 3

Table 2. Physical Properties of Latex

Solids Content (%)	pH	RVT Brookfield Viscosity	Surface Tension (dynes/cm)	Particle size (nm)	Stabilizer Type
48	9.5~11	40 mPas	30~35	180~210	Anionic

Table 3. Physical Properties of Aggregates

Aggregate	Max Size (mm)	Specific Gravity	Absorption (%)	Fineness Modulus
Fine Aggregate	≤ 5	2.6	0.71	2.88
Coarse Aggregate	13	2.57	1.1	6.2

2.3 CONCRETE MIXING AND CURING

Concrete mix proportions used in this study are shown in Table 4. The main experimental variables were a latex content and antifoam quantity. The latex contents were 0, 5, 10, 15, and 20% in the weight ratio of latex solid against cement, and the antifoam were 0, 1.6, 3.2, and 6.4% in the weight ratio of antifoam solid against latex solid.

No standard methods were established for mixing of latex modified concrete with rapid-setting cement. Thus, the concrete mixing containing latex followed to the previous study [1,4,6]. The mixing procedures were as follows: dry mixing fine and coarse aggregate for 30 seconds; additional dry mixing after including rapid-setting cement for another 30 seconds; and wet mixing with latex, water, antifoam and retarding admixture for another 60 seconds. After the specimens demolded in 3 hours, they were tested in order to check early-age strength development or air cured at a laboratory of 50% RH until testing.

2.4 TEST METHODS

Slump and Air Content Tests

Slump test and air content tests were carried according to KS F 2402 and KS F 2421, respectively. The slumps were measured just after pouring and every 5 minutes after that until it could be impossible in order to check the slump loss, because slump loss was very important factor in workability.

Setting Time Test

Setting time test was performed according to KS F 2436 in order to examine chemical instability between rapid-setting cement particle and latex particle or between hydrate particle and water. The instability may include abnormal setting problem, false setting, and retard setting.

Table 4. Mixing Proportions of Experimental Design

W/C (%)	Fine/Total Agg. (%)	Latex(%)	Unit Weight (lb/yd^3)				
			Cement	Water	Fine A	Coarse A	Latex
33	58	0	656	217	1,784	1,278	0
		5		182	1,741	1,242	69
		10		145	1,688	1,209	136
		15		109	1,640	1,173	205
		20		74	1,591	1,138	205
38	58	0	656	249	1,736	1,242	0
		5		214	1,687	1,207	69
		10		178	1,638	1,173	136
		15		139	1,591	1,138	205
		20		106	1,542	1,104	274

Compressive Strength and Flexural Strength Test

The compressive strength and flexural strength of RSLMC were measured according to KS F 2405 and KS F 2408, respectively, at 3 hours, 6 hours, 24 hours and 28 days. The measurements at 3 hours were for checking very-early-age strength development and 28 days for mid-term.

Rapid Chloride Permeability Test

Rapid chloride permeability test was performed according to ASTM C 1202 to evaluate the relative permeability of latex modified concretes. Vacuum apparatus was used to make the internal voids of specimen filled with water, which should be done for reliable test. The concrete permeability criteria established at ASTM C1202 is shown in Table 5, which allows us to estimate concrete's water permeability from rapid chloride permeability results.

Freeze-Thaw Resistance Test

The freeze-thaw resistance test was performed according to ASTM C 666 (Resistance of Concrete to Rapid Freezing and Thawing, Procedure A). The temperature at specimen center varied from 0 ^{o}F to 40 ^{o}F for 4 hours per cycle. 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.

3 TEST RESULTS AND ANALYSIS

3.1 SLUMP LOSS

Retarding admixture was used because it was very important to secure working time in case of using rapid-setting cement. It is also important to use proper quantity of retarding admixture because it is sensitive over temperature. The initial slump and slump loss with time elapse are shown in Figure 1. The quantity of retarding admixture was 0.3% that was proposed by cement manufacturing company and latex content was 15%. The main variable was quantity of antifoam. The initial slumps in all mixtures were satisfied to the targeted slump of 8±0.5 in and these were attributable to surfactant by surface tension between polymer particles and cement particles. It was possible to secure working time because slump loss with time elapse was smooth and maintained above 2 in after 40 minutes. The quantity of antifoam didn't affect to initial slump but made slump variation slump smoother as time elapsed.

Table 5. Concrete Permeability Criteria by Permeability Test of Chlorine Ion

Coulombs (Q)	Permeability Rating
Above 4,000	High
2,000 ~ 4,000	Moderate
1,000 ~ 2,000	Low
100 ~ 1,000	Very Low
Below 100	Negligible

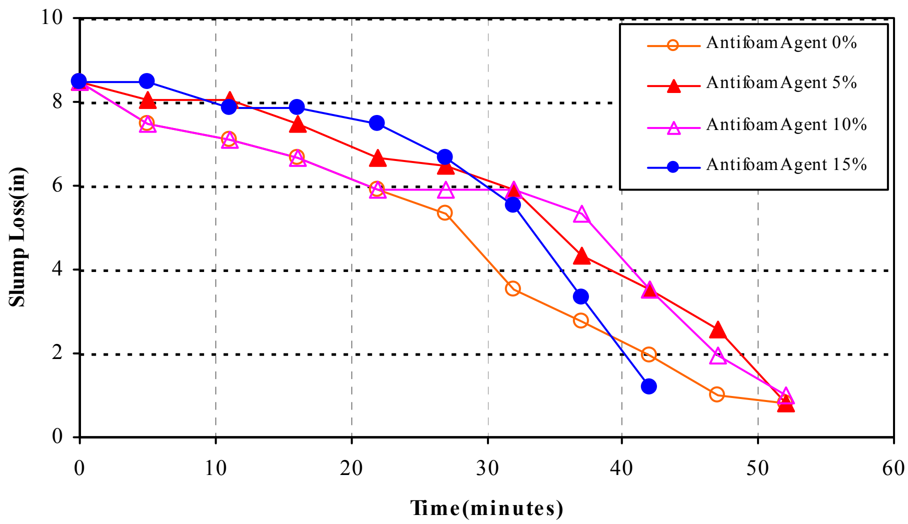

Figure 1. Slump Loss of RSLMC by Antifoam Contents

3.2 SETTING TIMES

The initial and final setting times were measured in order to evaluate the stability of concretes and to check the workability. The initial and final setting times of rapid-setting concrete without any latex (RSC) were 37 and 42 minutes, respectively, but those of concrete with 5% latex were 35 minutes and 38 minutes, respectively. These indicated that initial and final setting times of rapid-setting cement with latex were shorter than those of rapid setting cement without latex. Thin microfilm was produced on the surface of cement paste by addition of latex.

3.3 COMPRESSIVE STRENGTH DEVELOPMENT

Effect of Antifoam Content

The antifoam was used to restrain excessive air, which had occurred in latex modified concrete mixing with rapid-setting cement at previous pilot test. The amounts of antifoam were 0, 1.6, 3.2, and 6.4% in the weight ratio of antifoam solid to latex solid. The variations of air contents with antifoam contents are shown in Figure 2. In this figure, air content was 8% without antifoam, 3.0% with 3.2% antifoam, and 2.1% with 6.4% antifoam. Air contents of RSLMC decreased as the amount of antifoam increased.

Table 6 shows the compressive strength developments of RSLMC with times and amount of antifoam. The early-age compressive strength after 3 hours at 1.6% antifoam (at constant water-cement ratio of 38%) was 2,901psi, 20% larger than at 0% antifoam, and 6% and 16% larger than at 3.2% and 6.4% antifoam, respectively. While, the early-age compressive strength at 33% W/C was the highest (3,612psi) at 3.2% antifoam followed by 1.6%, 6.4% and 0% antifoam. The highest compressive strength developments after 6 hours were obtained at or near 1.6% antifoam. Thus, 1.6% of antifoam could be the optimum quantity in terms of compressive strength development of RSLMC.

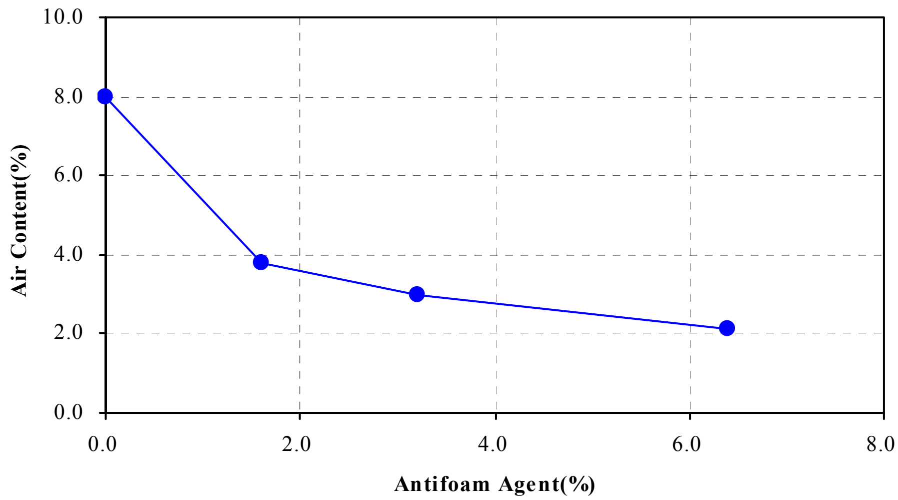

Figure 2. Variation of Air Contents with Antifoam Contents

Table 6. Compressive Strength Developments of RSLMC with Antifoam

W/C (%)	Latex (%)	Antifoam Contests (%)	Compressive strength (psi)			
			3 hrs	6 hrs	24 hrs	28 days
38	15	0	2,403	2,560	3,341	5,005
		1.6	2,901	3,185	3,697	6,044
		3.2	2,716	2,944	3,342	5,802
		6.4	2,417	2,602	2,986	5,105
33	15	0	3,200	3,797	4,707	5,972
		1.6	3,356	4,821	5,532	6,797
		3.2	3,612	4,835	5,432	6,612
		6.4	3,256	3,911	5,105	6,243

Effect of Latex Content

Table 7 shows the compressive strength development of RSLMC with latex contents at constant targeted slump of 8±0.5 in, which is illustrated at Figure 3. The initial compressive strength development of RSC at 3 hours was low because of excessive unit water contents, but it became higher at 24 hours. The early-age compressive strength of RSLMC with 5, 10, and 15% latex decreased as latex content increased because the unit water content decreased. But, the early-age compressive strength with 20% latex was very low at early-age even though water-cement ratio was very low, and this might be due to excessive addition of latex contents. Decrease of compressive strength at early-age might be attributable to delayed hydration of rapid-setting cement and smaller bond strength between cement hydrate and aggregate which might be similar to wet gels. The compressive strength at long term increased as latex content increased because the unit water decreased in order to keep the same workability at all mixtures.

3.4 FLEXUAL STRENGTH DEVELPMENT

Effect of Antifoam Content

The flexural strength was found to be little influenced by antifoam contents at 3 hour strength development, but a little influenced at longer ages by increasing the amount from 1.6% to 3.2%. The flexural strength with 1.6% to 3.2% antifoam increased a little more than that without antifoam after 3 hours as shown in Table 8. The antifoam didn't affect to the initial and long-term flexural strength development of RSLMC except at 6.4% latex inclusion. The excessive usage of antifoam brings to reduction of flexural strength. It was found that overuse of antifoam over 6.4% made flexural strength keep almost constant after 6 hours. From the results of compressive and flexural strength, the proper amount of antifoam for RSLMC with 15% latex was 1.6% in weight ratio of antifoam solid to latex solid.

Table 7. Compressive Strength Developments of RSLMC with Latex Contents

Antifoam Content (%)	Latex (%)	W/C (%)	Compressive Strength (psi)			
			3 hrs	6 hrs	24 hrs	28 days
0	0	49	2,261	2,730	4,920	5,460
1.6	5	45	3,967	4,351	5,418	7,366
	10	39	3,683	4,223	5,275	7,906
	15	33	3,356	4,821	5,532	6,797
	20	28	2,204	4,479	5,233	6,343

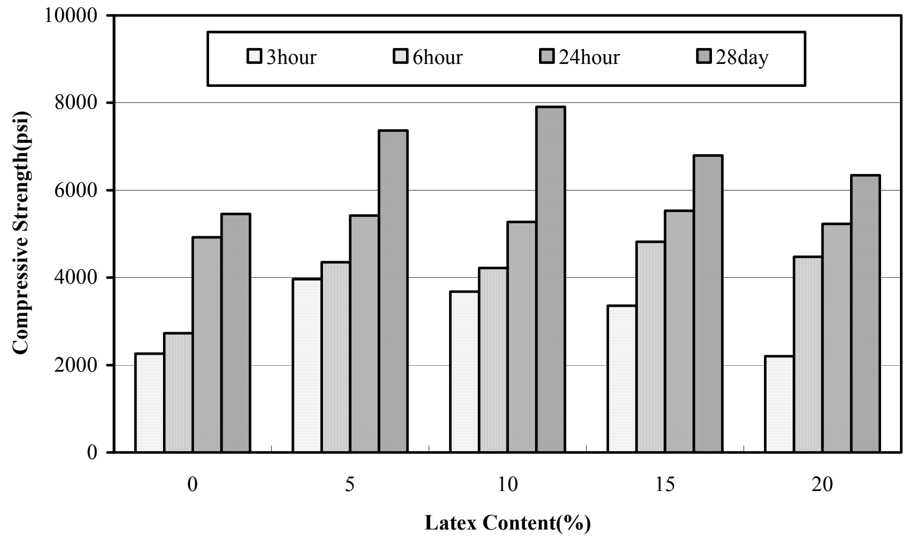

Figure 3. Compressive Strength Development of RSLMC with Latex Contents

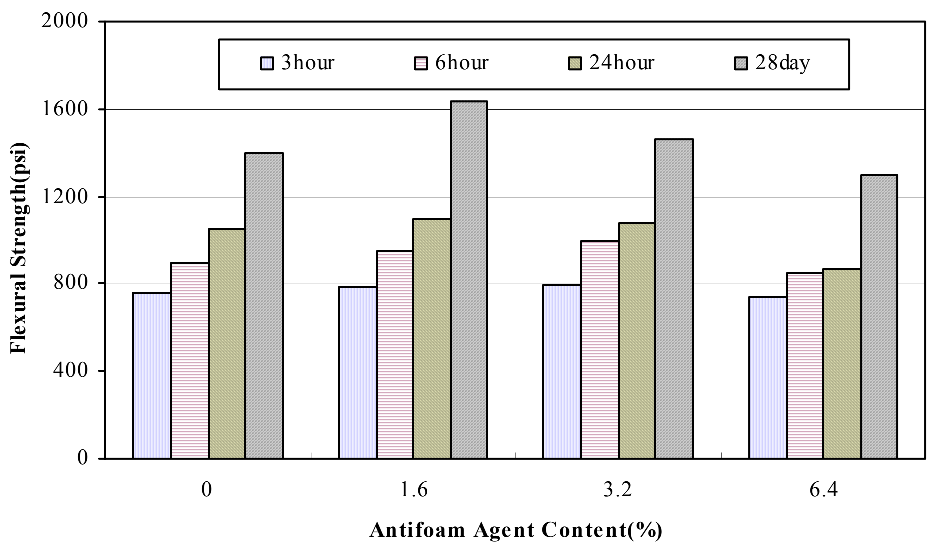

Figure 4. Flexural Strength Properties of RSLMC with Antifoam

Table 8. Flexural Strength Developments of RSLMC with Antifoam Contents

Latex (%)	W/C (%)	Antifoam Contents (%)	Flexural Strength (psi)			
			3 hrs	6 hrs	24 hrs	28 days
15	33	0	754	896	1,052	1,394
		1.6	782	953	1,095	1,635
		3.2	796	995	1,081	1,465
		6.4	739	853	867	1,294

Effect of Latex Content

Table 9 shows experimental results at a targeted slump of 8±0.5 in using the optimized content of 1.6% antifoam from previous section. The effect of latex content into flexural strength development at RSLMC was found to be large enough. The flexural strength at 3 hours is 357psi and 785psi at 0% and 15% latex content, respectively. The flexural strength criterion for opening to traffic in Korea, 640psi, was met after 3 hours at 15% and 20% latex content. The concrete had a higher flexural strength because the water-cement ratio was lower and because the plastic film produced higher bond strength between the plastic and aggregates. Figure 6 shows a microstructure of RSLMC at break section after flexural strength test, in which production of polymer film could be identified. Increasing of flexural strength for concrete with latex resin was considered due to filling void inside concrete with latex and production of film surrounding surface of aggregates which increase adhesion between the materials. The more latex is mixed the bigger flexural strength could be obtained but compressive strength of concrete decreased when latex of over 15% was used. Accordingly proper extent of latex contents for RSLMC was 15% to cement content.

Table 9. Flexural Strength Developments of RSLMC with Latex Contents

Antifoam Content (%)	W/C* (%)	Latex (%)	Flexural Strength (psi)			
			3 hrs	6 hrs	24 hrs	28 days
0	49	0	356	668	683	910
1.6	45	5	597	882	953	1,379
	39	10	583	939	1,024	1,493
	33	15	782	953	1,095	1,635
	28	20	754	1,067	1,194	1,522

* When slump is 8 in.

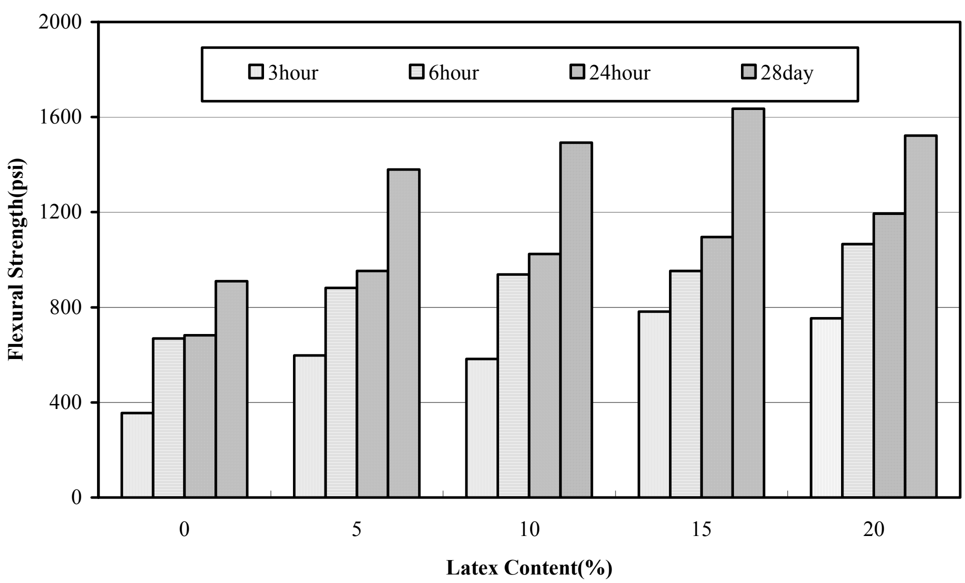

Figure 5. Flexural Strength Development of RSLMC with Latex Content

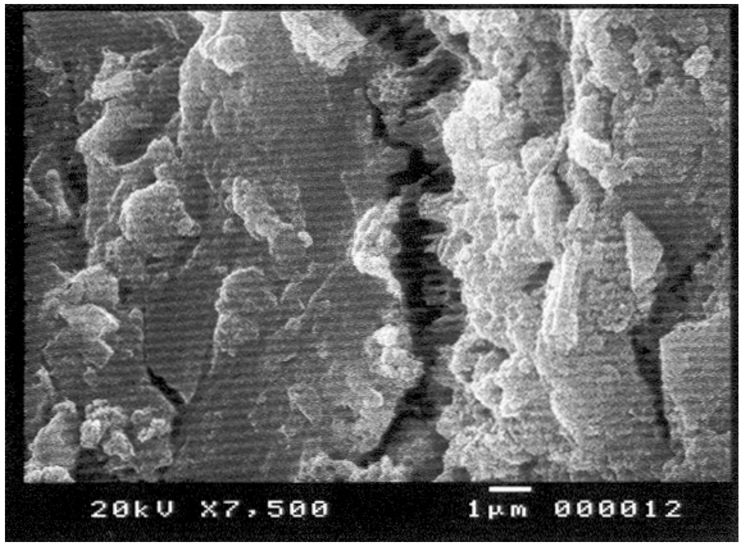

Figure 6. Microstructures of RSLMC Paste

3.5 RAPID CHLORIDE PERMEABILITY

Effect of Antifoam Content to Permeability

Table 10 shows the experimental results on rapid chloride permeability of RSLMC with antifoam contents. A general LMC with 15% latex showed about 1,000Q(coulombs), while RSLMC showed below 85Q indicating very low permeability. RSLMC with antifoam of 1.6% showed the lowest permeability, 54Q, which means almost impermeability material. This result might be due to filling effects of latex resin, air restraint by using antifoam and high blaine of rapid setting cement. Antifoam was found to be almost non-influencing to rapid chloride permeability by indicating below 100 Q at all mixtures except for 4.8 % antifoam content.

When antifoam was not added and resulted in 8% air content, the chloride permeability was very low, indicating that influence of antifoam for permeability was relatively low. These were because the latex film wrapped surround of void and restrained permeation of chloride ion though the latex film.

Table 10. Rapid Chloride Ion Permeability of RSLMC with Antifoam Contents

Antifoam (%)	Coulombs (Q)	Latex (%)	Slump (in.)	Curing days
0	79	15	8±0.5	28
1.6	54			
3.2	68			
4.8	85			

Table 11. Rapid Chloride Permeability of RSLMC with Latex Contents

Latex (%)	Coulombs (Q)	W/C (%)	Slump (in.)	Curing days
0	1,312	49	8 ± 0.5	28
5	1,229	45		
10	337	39		
15	68	33		
20	23	28		

Effect of Latex Content to Permeability

Table 11 shows the experimental results on rapid chloride permeability of RSLMC with latex contents at an equal targeted slump of 8±0.5 in. The total passing charges decreased from 1312Q to 23Q as latex contents increased from 0 to 20%. This meant influence of latex contents for permeability to be very big. When latex contents increased to 10%, 15% and 20% the rapid chloride permeability decreased by 74%, 95% and 98%, respectively. As a result, the rapid chloride permeability was found to be affected significantly by latex content. It decreased as latex content increased. However, an excessive use of latex over 15% was not effective in decreasing further rapid chloride permeability.

3.6 FREEZE-THAW RESISTANCE

Effect of Antifoam Content to Freeze- Thaw Resistance

Figure 7 shows the relative dynamic modulus of elasticity of RSLMC with antifoam at 15 % of latex content. The antifoam varied 0, 1.6, 3.2, 4.8, and 6.4%. When the quantity of antifoam increased form 0% to 1.6% the performance of RSLMC to dynamic modulus of elasticity became better rapidly keeping it above 90% after 235 cycles of freezing and thawing. When antifoam was over 3.2% the relative dynamic modulus of elasticity maintained over 90% until 300 cycles of freezing and thawing. But, an additional performance was not measured even at further antifoam usage of 3.2, 4.8, and 6.4%. There was almost no difference in the relative dynamic modulus of elasticity among them. The antifoam in RSLMC attributed to not only increase of strength due to air restraint but also resistance of freeze and thaw.

Effect of Latex Content to Freeze-Thaw Resistance

The variation of relative dynamic modulus of RSLMC with latex contents is shown at Figure 8. 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. The overall performances did not make big difference between RSC and RSLMC in terms of relative dynamic modulus of elasticity and durability factor. Within the range of this study, both RSLMC and RSC showed good freeze-thaw resistance although the latex-modified exhibited superior performance.

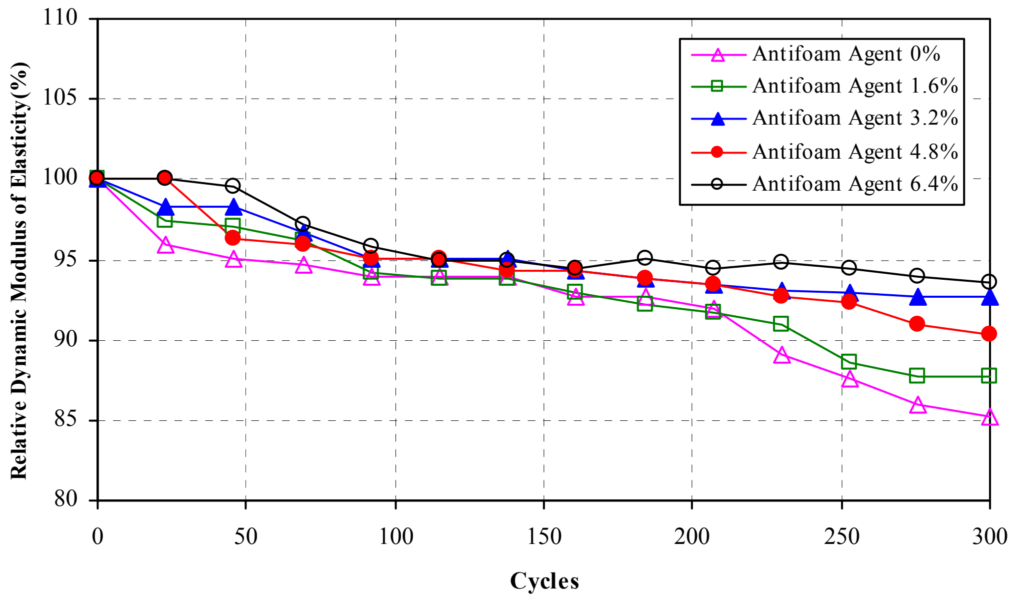

Figure 7. Relative Dynamic Modulus of Elasticity with Antifoam

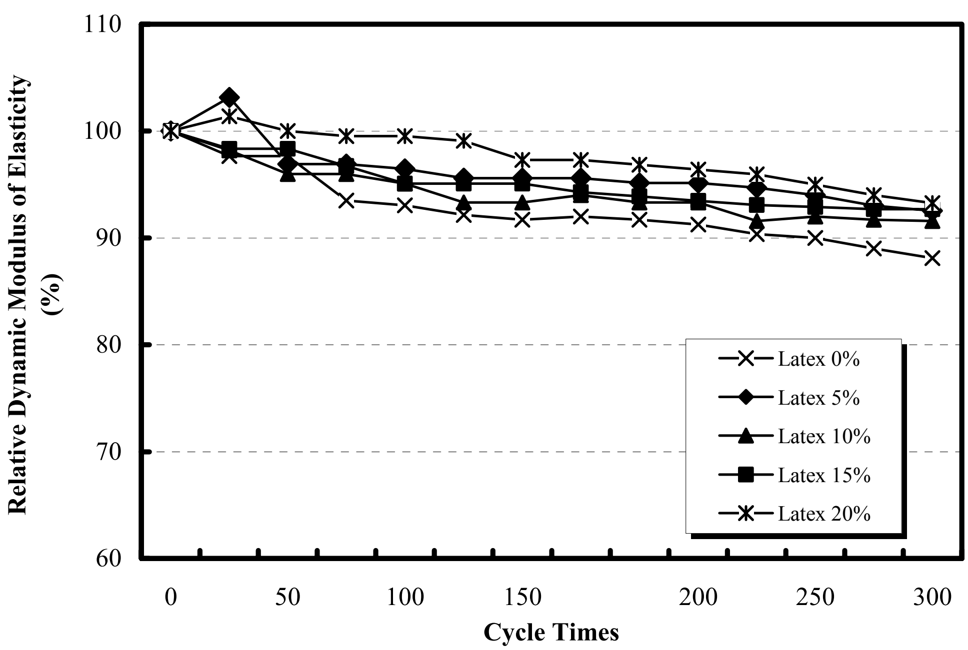

Figure 8. Relative Dynamic Modulus of Elasticity with Latex Contents

4 CONCLUSIONS

Latex modified concrete with rapid setting cement for concrete bridge deck overlay was developed for opening to the traffic after 3 hours of concrete placement. The developed RSLMC was evaluated in terms of mechanical properties and durability. This paper presents only a part of development works concentrating on the effect of latex and antifoam on SB latex-modified concrete with rapid-setting cement. Conclusions are as following:

1. The initial slumps at all RSLMC mixtures were satisfied to the targeted slump of 8±0.5 in. It was possible to secure working time because slump losses with time elapse were smooth and maintained above 2 in after 40 minutes.

2. The early-age compressive strength within 15% latex content decreased as latex content increased because the unit water content decreased. But, that with 20% was very low at early-age even though water-cement ratio was very low, and this might be due to excessive addition of latex contents.

3. The flexural strength was found to be little influenced by antifoam contents at 3 hour strength development, but a little influenced at longer ages by increasing the amount from 1.6% to 3.2%. The excessive usage of antifoam brings to reduction of flexural strength.

4. The effect of latex content into flexural strength was found to be large enough. The flexural strengths at 3 hours were 357psi and 785psi at 0% and 15% latex content, respectively. The flexural strength criterion for opening to traffic in Korea, 640 psi, was met after 3 hours at 15% and 20% latex content. From the results of compressive and flexural strength, the proper amount of antifoam for RSLMC with 15% latex was 1.6% in weight ratio of antifoam solid to latex solid.

5. The latex-modified with 1.6% antifoam showed the lowest permeability, 54Q, which means almost impermeability material. This result might be due to filling effects of latex resin, air restraint by using antifoam and high blaine finenesses of rapid setting cement. Antifoam was found to be almost non-influencing to rapid chloride permeability by indicating below 100 Q at all mixtures except for 4.8 % antifoam content.

6. The total passing charges decreased from 1,312Q to 23Q as latex contents increased from 0 to 20%. The rapid chloride permeability was found to be affected significantly by latex content. It decreased as latex content increased. However, an excessive use of latex over 15% was not effective in decreasing further rapid chloride permeability.

7. The relative dynamic modulus of elasticity of the latex mixtures maintained above 90% after 300 cycles, while the mix without latex dropped under 90% after 250 cycles. Within the range of this study, both RSLMC and RSC showed good freeze-thaw resistance, although the latex-modified exhibited superior performance.

REFERENCES

1. Yun, K.K., Hong, C.W., Lee, J.H. and Choi, S.L., "Strength Development and Permeability of Latex-Modified Concrete with Rapid-Setting Cement", *Korea Concrete Institute*, Vol.14, No.3, June 2002, pp299~306.
2. Sprinkel, M.M., "Very-Early-Strength Latex-Modified Concrete Overlay, " *Technical Report*, VTRC99-TAR3, Virginia Transportation Research Council, December, 1998.
3. Sprinkel, M. M., "High-Early- Strength Latex Modified Concrete Overlays", *Transportation Research Record 1204*, TRB, National Research Council, Washington, D.C, 1988, pp42~51.
4. Ohama, Y., "*Handbook of Polymer-Modified Concrete and Mortars Properties and Process Technology*," NOYES PUBLICATIONS, 1995.
5. Kuhlmann, L. A., "Performance History of Latex -Modified Concrete Overlays", *ACI Publication SP-69: Application of Polymer Concrete*, 1981, pp205-218.
6. Yun, K.K., Lee, J.H., Hong, C.W., Kim, K.H. and Kim, T.K., "Field Applicability Evaluation of SB Latex-Modified Concrete for Concrete Bridge Deck Overlay", *Korean Society of Pavement Engineers*, Vol.3, No.4, December 2001, pp93~103.