International Journal of Concrete Structures and Materials
DOI 10.1186/s40069-018-0261-8
ISSN 1976-0485 / eISSN 2234-1315

Durability of Latex Modified Concrete Mixed with a Shrinkage Reducing Agent for Bridge Deck Pavement

Byung Jae Lee[1], and Yun Yong Kim[2],*

(Received September 27, 2017, Accepted February 9, 2018)

Abstract: Latex modified concrete (LMC) is used for a bridge deck pavement method that was introduced in Korea in the 2000s, and it is currently the concrete pavement method being used for most highway bridges. It has been recommended that mixing with latex approximately 15% in terms of polymer-cement ratio (P/C ratio) by weight showed no occurrence of cracks with sufficient tensile strength and bond strength of LMC. However, many cracks occur in the actual field mostly due to drying shrinkage of concrete, requiring frequent repair. Therefore, this study examined the feasibility of applying a shrinkage reducing agent(SRA) that could reduce plastic shrinkage cracks at early age as well as drying shrinkage cracks of LMC. Based on the test results, it was confirmed that adding a shrinkage reducing agent could secure the durability without affecting the fresh and hardened properties of LMC. The compression strength test results presented a 1.7–5.7% improvement in strength to the SRA mixture compared to the plain mixture. Length change test results indicated that SRA mix conditions presented more outstanding performance compared to mix conditions with the expansive admixture. The amount of shrinkage reducing agent suitable for achieving performance requirements in length change, crack resistance, chloride ions penetration resistance and scaling resistance, was evaluated as 3% by weight ratio of binding material under the limited condition of the present study.

Keywords: bridge deck pavement, shrinkage reducing agent, latex modified concrete, durability.

1. Introduction

In recent years, the construction of large bridges has been promoted in Korea with the aim of revitalizing tourism in the West Sea and the South Sea, including the development of more than 36 bridges (bridges connecting an island and the land and bridges connecting islands) scheduled until 2020. Various studies regarding the pavement of such bridges are being carried out actively at home and abroad, as a method of protecting the bridge deck from impacts, rain water, chloride and other environmental conditions is required. The bridge deck pavement method used most frequently in Korea is the latex modified concrete (LMC) bridge deck pavement method, which was introduced in the 2000s (American Concrete Institute 2008). LMC is produced by mixing ordinary concrete with latex in which polymer produced by copolymerizing styrene monomer and butadiene monomer in the water is distributed evenly in a certain quantity, significantly improving the durability in comparison to ordinary concrete. It has been reported that the latex used in LMC fills micro-pores and forms a film layer to prevent the penetration of moisture or chloride from the outside, leading to an improvement of the durability (Kim et al. 2001; American Concrete Institute 2000; Wang et al. 2015). However, it is difficult to control the cracks of LMC due to the construction conditions of bridge deck pavement in which significant water evaporation occurs, and as a result, plastic shrinkage cracks and drying shrinkage cracks often occurs as shown in Fig. 1 (Yun et al. 2002; Choi et al. 2016).

Various technologies for reducing cracks that can occur in concrete due to various factors have been developed and used. Recently, shrinkage reducing agent has been employed to reduce drying shrinkage and the cracks. The shrinkage reducing agent reduces the capillary tension during drying, leading to reduction of shrinkage and cracks (Park et al. 2013; Qian et al. 2006). Therefore, the mechanical properties and durability performance of latex modified concrete for each mixing ratio of shrinkage reducing agent were analyzed and field applicability was evaluated in this study in order to evaluate the feasibility of using the shrinkage reducing agent to reduce the cracks that may occur when LMC is used for bridge deck pavement.

2. Principle of Shrinkage Reducing Agent

Drying shrinkage is considered to be a physical behavior accompanied by the evaporation of moisture, and the most

[1]R&D Center, JNTINC CO. LTD., 9, Hyundaikia-ro 830 beon-Gil, Hwaseong-City, Gyeonggi-Do 18284, Republic of Korea.

[2]Department of Civil Engineering, Chungnam National University, Daejeon 34134, Republic of Korea.

*Corresponding Author; E-mail: yunkim@cnu.ac.kr

Published online: 26 February 2018

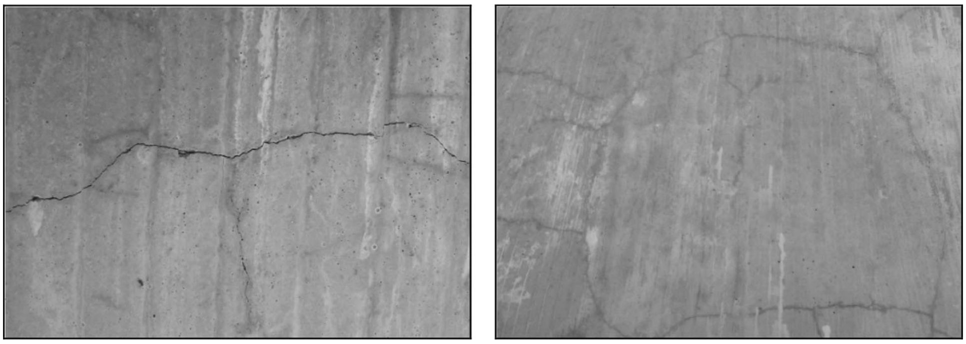

Fig. 1 Case of crack occurrence in the LMC bridge deck pavement.

valid theory among various theories for its mechanism of action is the capillary tension theory. A meniscus is formed in a micro-pore in concrete, due to the capillary tension existing with the surface tension of water when water evaporates. Drying shrinkage is the mechanical deformation of the matrix caused by a driving force, the capillary tension (Fig. 2) (Han et al. 2006; Kang et al. 2016). The capillary tension may be shown as the coefficient of radius curvature and the surface tension, and when water evaporates due to drying, the radius curvature decreases and the capillary tension increases, so that shrinkage occurs.

$$\Delta p = \gamma \left[\frac{1}{r_2} + \frac{1}{r_2} \right] \quad (1)$$

Where, Δp: Capillary tension

γ: Surface tension of liquid

r_1, r_2: Main radius curvature of liquid (m)

When the shrinkage reducing agent is used, the surface tension of water is lowered, reducing tensile stress and drying shrinkage. It is reported that adding the shrinkage reducing agent could reduce the surface tension of capillary water to 30 $\sim$ 45 mN/m, decreasing drying shrinkage (Kim et al. 1997).

3. Experiment Plan and Method

3.1 Test Variables

In order to evaluate the properties of the LMC mixed with the shrinkage reducing agent, the mixing ratio of the shrinkage reducing agent used in ordinary concrete was reviewed in advance, and the mixing ratios (0, 1.0, 2.0, 3.0, 5.0%) in comparison to the binder weight were decided. The mix proportions are displayed in Table 1.

A series of specimens was additionally produced using expansive admixture (binding material replacement ratio-1%) and fiber (binding material $\times$ 0.2) and examined for the comparative evaluation of admixture materials used for reducing cracks of LMC. Mixing was carried out through a separate charging to carry out dry mixing for 30 s with

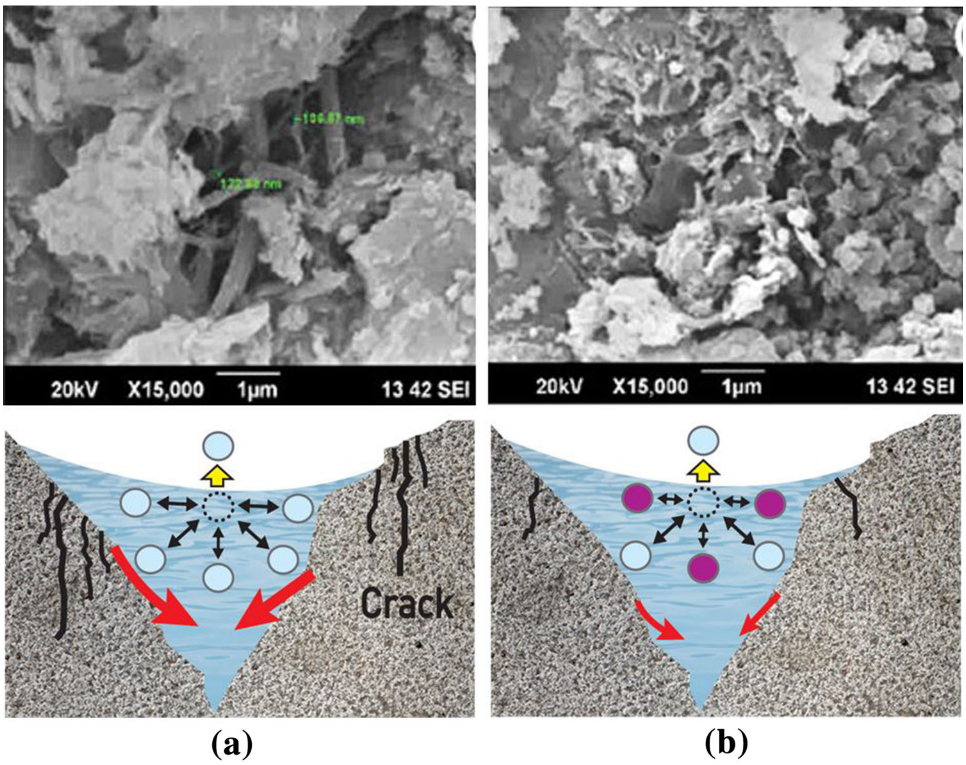

Fig. 2 Principle and effects of shrinkage reducing agent. **a** plain and **b** use of shrinkage reducing agent.

Table 1 Table of mix proportions.

Mix no.	W/C	S/a	P/C	Unit mass (kg/m^3)					
				W	C	LATEX	S	G	SRA
Plain	35%	55%	15%	72	400	128	898	746	–
SRA 1				68					4
SRA 2				64					8
SRA 3				60					12
SRA 5				52					20
ED 1	35%	55%	15%	72	396	128	898	746	ED: 4
Fiber 0.2				72	400				Fiber: 0.6

W water, *C* cement, *S* sand, *G* gravel, *SRA* Shrinkage-reducing agent, *ED* Expansion admixture.

aggregate and cement, followed by wet mixing of them with latex and water for 90 s. LMC specimens were cured in a thermostatic chamber (temperature of 20 °C and 60% humidity).

3.2 Materials for Use

3.2.1 Cement

Ordinary Portland cement with a density of 3.14 g/cm^3 and fineness of 3200 cm^2/g manufactured by S company in Korea was used for the cement in this study.

3.2.2 Latex

The latex used in this study was produced by adding the surfactant and the stabilizer to a milky liquid material produced from high molecular copolymer consisting of styrene and butadiene as main monomers. The physical properties of the latex are shown in Table 2.

3.2.3 Aggregate

Crushed aggregate with a maximum size of coarse aggregate of 13 mm was used for the aggregate in this study in consideration of the thickness of the bridge deck pavement, and natural river sand was used as fine aggregate. The physical properties of the aggregate are shown in Table 3.

3.2.4 Shrinkage Reducing Agent

A glycol ether-based product was used for the shrinkage reducing agent in this study. The properties of the shrinkage reducing agent are shown in Table 4.

3.3 Test Method

3.3.1 Properties of Fresh Concrete

In order to evaluate the fresh properties of LMC mixed with the shrinkage reducing agent, the slump and air content tests were carried out according to KS F 2402 and KS F 2421.

3.3.2 Strength Properties

To assess the strength properties according to the mixing conditions, the LMC compressive strength tests were performed at the 7 and 28 days of aging as per KS F 2403. For the bond strength, concrete slab substrates (300 × 300 × 50 mm) were produced with the concrete of 40 MPa compressive strength in advance and overlaying a 50 mm-thick LMC at the 28 days of aging. The measurement was carried out in accordance with ASTM C 1583-04 (ASTM 2004).

3.3.3 Evaluation of Durability Performance

The length change test, crack resistance test, chloride ions penetration resistance and scaling resistance test were carried out to evaluate the durability performance. For the length change test, a both-end flange type gauge was embedded in the middle of a 100 × 100 × 400 mm prismatic shaped LMC specimen and the shrinkage was measured until the 28 days of aging. For the crack resistance evaluation, ring specimens were produced in accordance with AASHTO PP 34 99 and the occurrence of cracking was visually observed until the 56 days of aging (AASHTO 2005).

The chloride ions penetration resistance was evaluated by measuring the charge passed at the 28 days of aging in accordance with KS F 2711 (Korean Standards Association 2017).

For the scaling test, the quantitative evaluation was carried out in accordance with SS13 72 44, the test standards used in Sweden (Fig. 3) (Swedish Standard Institute 2005). For the measurement method, a 150 × 150 × 50 specimen was produced, a sodium chloride solution was sprayed on the top side of the specimen, the process of freezing (16–18Hr) and thawing (6–8Hr) was repeated for 56 cycles, and then the rate of mass change was measured.

Table 2 Properties of latex.

Material	Average particle size (nm)	Solid contents (%)	Viscosity (cps)	Ionicity	pH	Appearance
SB Latex	184.6	47.1	384	Nonionic	9.5	White liquid

Table 3 Properties of aggregate.

Type	Max Size (mm)	Density (g/cm^3)	Absorption (%)	F.M
Fine aggregate	< 5	2.6	0.71	2.98
Coarse aggregate	13	2.7	0.97	6.3

Table 4 Properties of SRA.

Type	Moisture content (%)	Density (g/cm^3)	pH	Active ingredient (%)
Glycol ether type	28.2	0.98	6.5	71.8

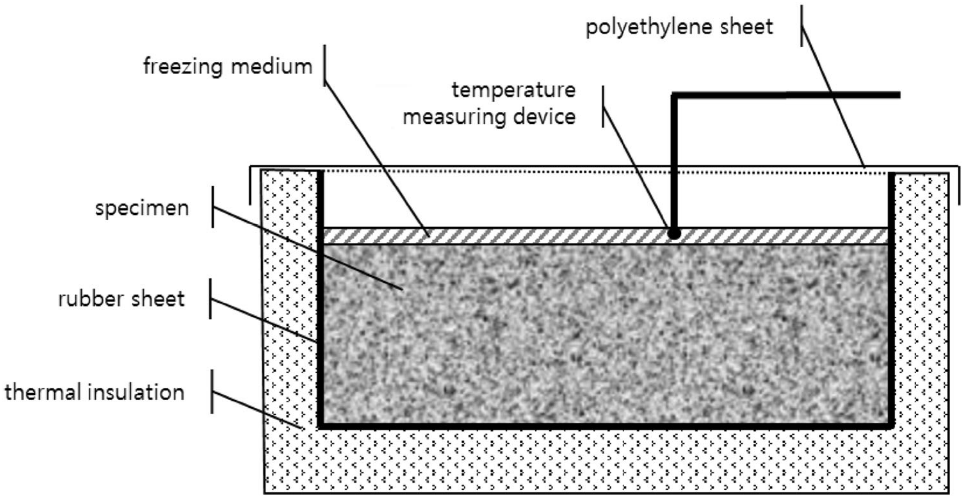

Fig. 3 Scaling resistance test image.

4. Experimental Results and Discussions

4.1 Fresh Properties

The test results of fresh properties of LMC are shown in Fig. 4. Slumps of all SRA mixes satisfied the requirement of 160–220 mm for LMC presented by the Korea Expressway Corporation. Slump of SRA 5 mix was approximately 10% smaller compared to the other SRA mixes. It is considered that this was caused by an increase in air content of SRA 5 mix. When the expansive admixture was used, a decrease in air content and a slight increase in the slump were shown, and the workability of concrete decreased when it was mixed

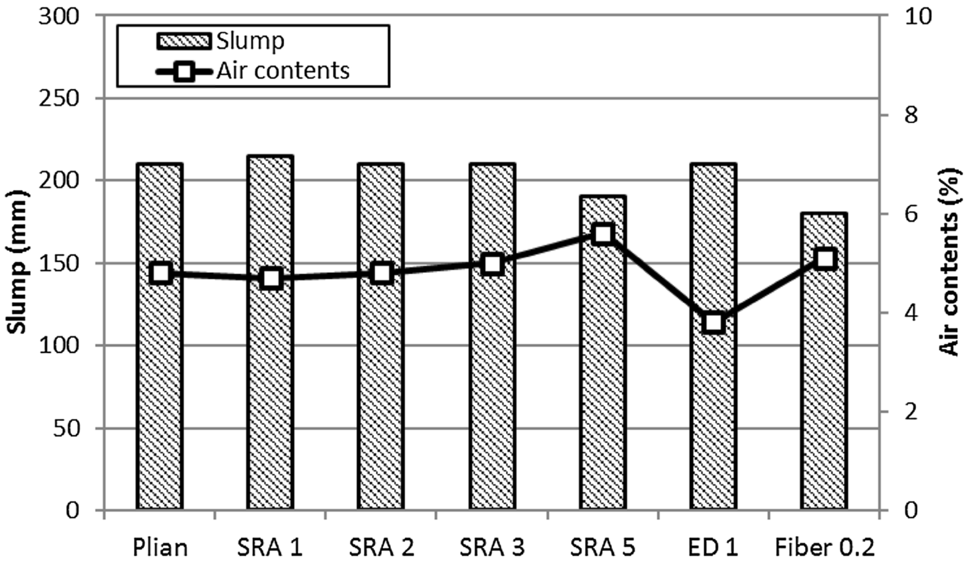

Fig. 4 Fresh properties.

with fiber, leading to a lower slump compared to other mixes.

4.2 Compressive Strength and Bond Strength

The result of the strength properties evaluation of LMC for each mixing condition is shown in Fig. 5. The compressive strength at 7 days increased with the mixing ratio of the shrinkage reducing agent, but it decreased when the mixing ratio was 5%. The compressive strength at 28 days for all mixes satisfied 27 MPa that is the strength requirement of the Korea Expressway Corporation. The compressive strength at 28 days of SRA 5 was lower than that of SRA 3. It is considered that this was because a large amount of mixing water was replaced by the shrinkage reducing agent so that the amount of mixing water required to have a reaction with cement decreased significantly. When LMC was mixed with expansive admixture, the compressive strength was similar to that of Plain mix. Mixing with nylon fiber also had no significant effect on the compressive strength.

In terms of the bond strength, fracture of slab substrate occurred in all mixing conditions, but the interfacial fracture occurred only in the mixture with fiber. All mixing conditions satisfied the bond strength requirement of 1.4 MPa presented by the Korea Expressway Corporation (Korea Highway Corporation 2012).

4.3 Durability Performance

4.3.1 Length Change Test

The test results of the length change ratio of LMC are shown in Fig. 6. Plain mix without the shrinkage reducing agent showed the largest shrinkage, and the smallest shrinkage was shown when it was mixed with the shrinkage reducing agent in an amount of 0.3%. When it was mixed with the shrinkage reducing agent in an amount of 0.5%, the shrinkage decreased in comparison to Plain mix, but a larger shrinkage was shown compared to SRA 2 and SRA 3. This is most likely due to the increase in air content of SRA 5 mix. ED 1 mix specimen expanded at early ages then it shrank. Fiber 0.2 mix showed a similar length change to Plain mix.

4.3.2 Crack Resistance

We carried out the restrained shrinkage test with ring specimen in order to evaluate the crack resistance performance of LMC. It was found that no crack occurred in all mixes until the age of 56 days, meeting the requirement specified by the Korea Expressway Corporation. However, it is necessary to verify whether a crack occurs or not in long-term aging in the future.

4.3.3 Chloride Ions Penetration Resistance

The measurements of chloride ions penetration resistance at 28 days and 56 days are shown in Fig. 7. The highest chloride penetration performance was shown when the shrinkage reducing agent was mixed at a ratio of 3%. When it is mixed with the shrinkage reducing agent, the matrix inside the LMC becomes dense, increasing the durability. It was confirmed that when it was mixed with the expansive admixture, it showed a higher durability than Plain, but such durability was slightly lower than the performance of SRA mixes. Fiber 0.2 mix showed the lowest chloride ions penetration resistance. This is likely because hydrophilic fiber and the fiber-matrix interface worked as a path of chloride ions penetration, however, the effect of fibers needs to be further investigated in a follow-up study. It was confirmed that all mixtures satisfied the requirements of the Korea Expressway Corporation, which are 2000 °C at 28 days and 1000 °C at 56 days.

Through analyzing the correlation between the result of the compressive strength test and the result of the chloride ions penetration resistance test, a high correlation of 92.5% as shown in Fig. 8 is shown, indicating that the high strength LMC showed high resistance to chloride ions penetration..

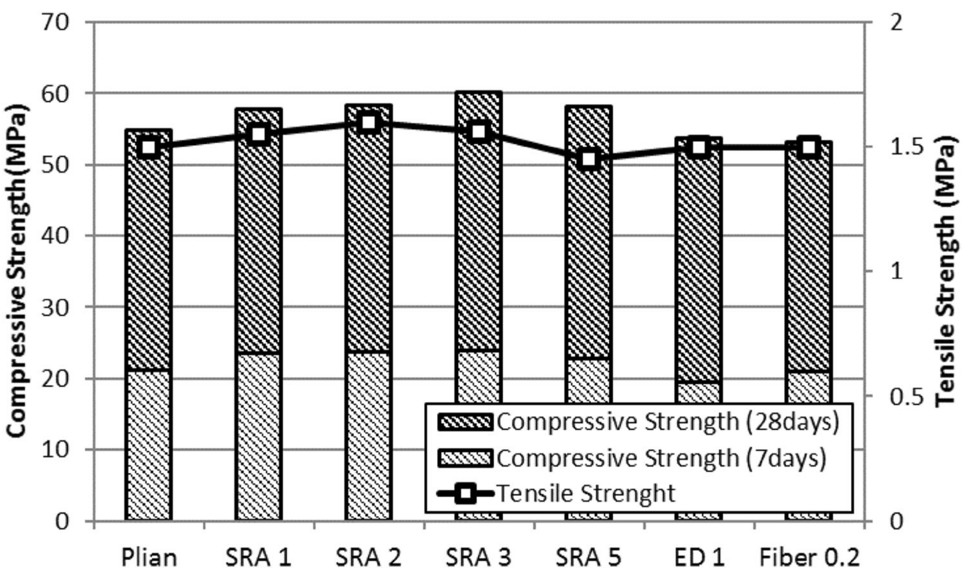

Fig. 5 Compressive strength and bond strength.

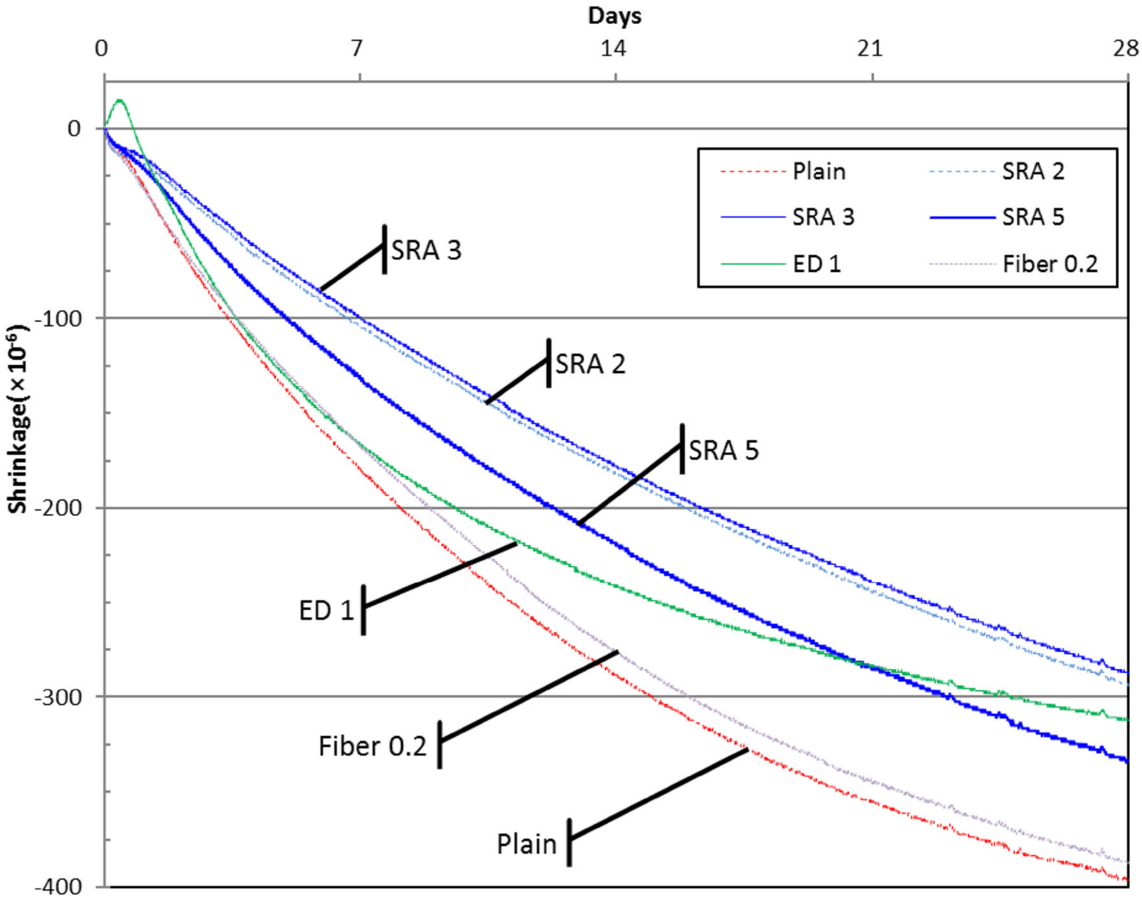

Fig. 6 Length change test.

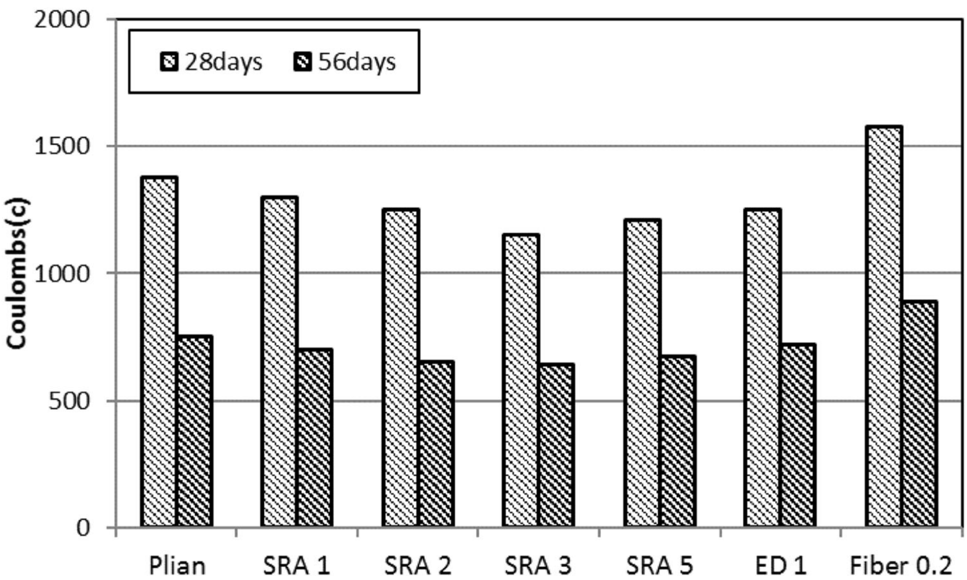

Fig. 7 Chloride ions penetration resistance.

4.3.4 Scaling Resistance Test

Following a snowfall during winter season, chloride-based deicing agents are sprayed. However, spraying chloride-based deicing agents causes the combined deterioration of chloride attack and freeze–thaw damage to concrete structures. Therefore, the scaling test for the LMC specimen mixed with the shrinkage reducing agent was carried out in this study. In the test, SRA 3 mix that showed excellent fresh and hardened performance among SRA mixtures was compared with Plain at 28 days and 56 days. The result is as shown in Fig. 9. In comparison to Plain, SRA 3 mix showed an increase in scaling resistance of 41.8–42.9% in terms of scaling mass. Also, SRA 3 mix showed the scaling mass ratio of 1.75, which is defined as the ratio of scaling mass at 56 days to scaling mass at 28 days, while Plain mix showed the scaling mass ratio of 1.90. This indicates SRA 3 mix

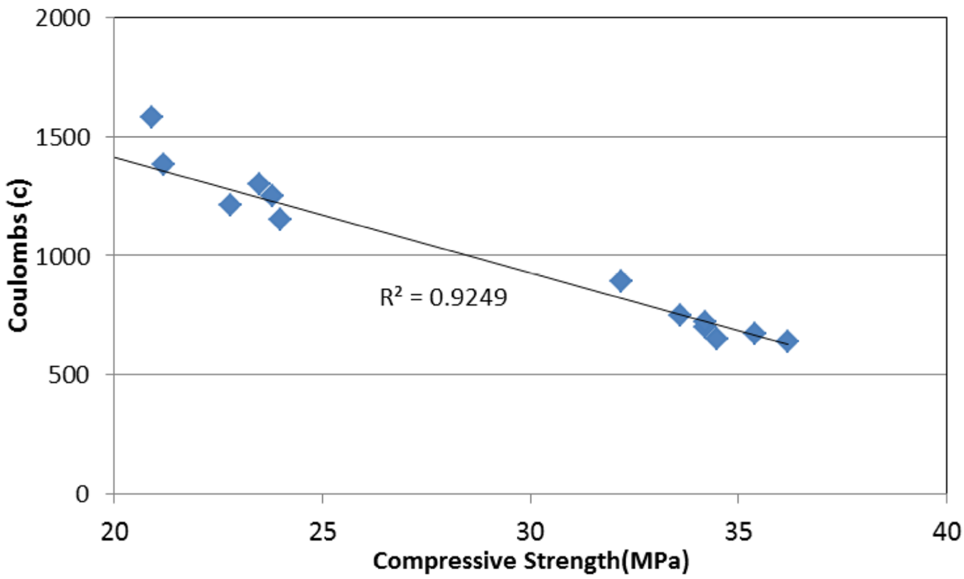

Fig. 8 Correlation between the compressive strength and chloride ions penetration resistance test results.

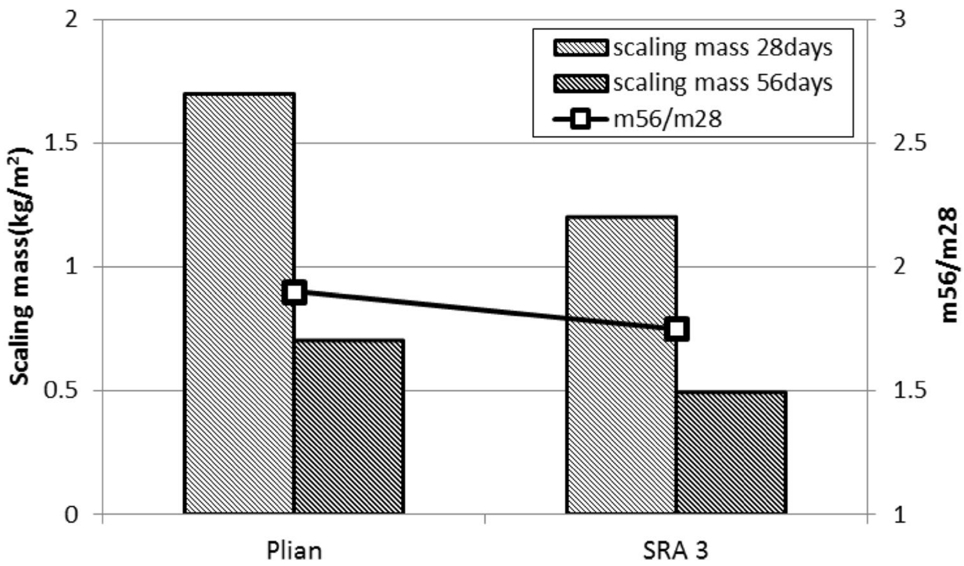

Fig. 9 Scaling resistance test.

exhibited an enhanced scaling performance in terms of scaling mass ratio as well as scaling mass. SRA 3 mix exhibited the result of "Good" grade in the evaluation grades presented by the standards in Sweden, which was higher than the "Acceptable" grade for Plain.

5. Evaluation of Crack Resistance in Field

A field test was carried out to evaluate the crack resistance of the LMC using the shrinkage reducing agent. SRA 3 mix was employed for the field test because SRA 3 mix showed the best performance in the prior tests. A 2 m × 2 m × 0.1 m slab was cast in a part of pavement, as shown in Fig. 10. Cracks occurred was visually observed through monitoring until the age of 56 days. As a result of the experiment, no crack was found in the slab, indicating that the performance of the shrinkage reducing agent was confirmed. Further application and verification need to be performed on a larger size of bridge deck pavement.

6. Conclusions

In this study, the mechanical properties and durability performance of latex modified concrete for each mixing ratio of shrinkage reducing agent were analyzed in order to evaluate the feasibility of using the shrinkage reducing agent to reduce the cracks that may occur when LMC was used for the bridge deck pavement, and the results are as shown below.

1 Mixing with the shrinkage reducing agent had insignificant effects on the properties of fresh concrete, but when

(a) (b)

Fig. 10 Evaluation of crack resistance in field. a after placement and b after 56 days.

concrete was mixed with over 5% shrinkage reducing agent, excessive air content and slump loss occurred. In terms of the compressive strength and bond strength, SRA 3 mixing showed the highest compressive strength and bond strength, and the compressive strength and bond strength decreased in other mixing conditions. For the expansive admixture and fiber reinforcement, similar mechanical properties with Plain were shown, indicating that there were insignificant effects.

2 Through evaluating the shrinkage properties of LMC mixed with the shrinkage reducing agent, the SRA 3 mixing showed the lowest length change. In terms of crack occurrence, there was no crack developed under all mixing conditions in the crack resistance test for 56 days. However, it is necessary to verify whether a crack occurs or not in long-term aging in a follow-up study.

3 In the durability performance evaluation, it was confirmed that the high strength LMC showed high resistance to chloride ions penetration. In terms of the scaling resistance, an excellent result was also achieved as "Good" grade was shown when the shrinkage reducing agent was used. Also, no crack occurred in field test, indicating that shrinkage reducing agent could be applicable to the field.

4 In this study, we employed the shrinkage reducing agent to enhance the crack resistance of LMC for bridge deck pavement. Based on a series of the test results, it was found that the regulations of the Korea Expressway Corporation were satisfied in all conditions, and that the use of a shrinkage reducing agent within the prescribed range was favorable for securing performance. However, it is necessary to apply this to an actual bridge and monitor it for an extended period of time.

Acknowledgements

This research was supported by Basic Science Research Program through the National Research Foundation of Korea(NRF) funded by the Ministry of Science, ICT & Future Planning(No. 2015R1A5A1037548).

Compliance with Ethical Standards

Conflict of interest

The authors declare that there is no conflict of interest regarding the publication of this article.

Open Access

References

AASHTO PP 34-99. (2005). *Standard practice for estimating the cracking tendency of concrete*.

American Concrete Institute. (2000). *Standard Specification for Latex-Modified Concrete (LMC) Overlays*, ACI 548. p. 4–93

American Concrete Institute. (2008). *Building Code Requirements for Structural Concrete*, ACI 318-08, p. 473.

ASTM C 1583-04. (2004). Standard test method for tensile strength of concrete surfaces and the bond strength or tensile strength of concrete repair and overlay materials by direct tension (pull-off method)

Choi, J. Y., Joo, M.-K., & Lho, B. C. (2016). Effects of silica fume content and polymer-binder ratio on properties of ultrarapid-hardening polymer-modified mortars. *International Journal of Concrete Structures and Materials, 10*(2), 249–256.

Han, C. C., Han, M. C., Song, S. H., & Yoon, S. (2006). Drying shrinkage of concrete combining expansive additives and shrinkage reducing agent. *Journal of the Korea Concrete Institute, 18*(3), 398–404.

Kang, S.-T., Lee, K.-S., Choi, J., Lee, Y., Felekoğlu, B., & Lee, B. Y. (2016). Control of tensile behavior of ultra-high performance concrete through artificial flaws and fiber hybridization. *International Journal of Concrete Structures and Materials, 10*(3), 33–41.

Kim, K. H., Lee, J. M., Hong, C. W., & Yun, K. K. (2001). Permeability and freeze-thaw resistance of latex modified concrete. *Journal of the Korea Concrete Institute, 13*(5), 484–490.

Kim, W., Ohama, Y., & Demura, K. (1997). Drying shrinkage reduction of polymer-modified mortars using redispersible polymer powder by use of shrinkage-reducing agents. *Zairyo, 46*(1), 84–88.

Korea Highway Corporation. (2012). *Expressway construction guide specification*. pp.950–980.

Korean Standards Association (2017). *KS F 2711 Standard test method for resistance of concrete to chloride ion penetration by electrical conductance*.

Park, J. J., Yoo, D. Y., Kim, S. W., & Yoon, Y. S. (2013). Drying shrinkage cracking characteristics of ultra-high-performance fibre reinforced concrete with expansive and shrinkage reducing agents. *Magazine of concrete research, 65*(3-4), 248–256.

Qian, C. X., Geng, F., & Li, L. (2006). Mechanism and effect of shrinkage-reducing agent used in cement mortar. *Journal of Functional Materials, 37*(2), 287–291.

Swedish Standard Institute (2005). *SS 13 72 44 ED. 4. Concrete testing—hardened concrete scaling at freezing*.

Wang, M., Wang, R., Zheng, S., Farhan, S., Yao, H., & Jiang, H. (2015). Research on the chemical mechanism in the polyacrylate latex modified cement system. *Cement and Concrete Research, 76,* 62–69.

Yun, K. K., Lee, J. H., & Hong, C. W. (2002). Properties of Latex modified concrete with rapid-setting cement using antifoamer. *Journal of the Korea Society of Civil Engineer, 22*(5-A), 1143–1151.