Journal of Ceramic Processing Research. Vol. 21, No. 2, pp. 164~169 (2020)
(Received 5 August 2019, Received in revised form 18 March 2020, Accepted 27 March 2020)
https://doi.org/10.36410/jcpr.2020.21.2.164

J O U R N A L O F
Ceramic Processing Research

The study on the effect of calcium chloride deicing agent and concrete compressive strength on scaling

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This experimental study investigated the durability degradation of concrete exposed to freezing and thawing and chloride intrusion. In order to observe the degree of the degradation, 24 MPa, 35 MPa and 60 MPa concretes were used with 4% and 12% calcium chloride solution as freezing water for scaling resistance and freeze - thaw resistance tests. The results show that 24 MPa and 35 MPa concrete had a relatively large decrease in durability due to the freeze-thaw resistance and scaling resistance, but the 60 MPa concrete was not deteriorated significantly. In addition, when the concentration of the solution of calcium chloride was 4%, the degradation of durability was most remarkable. The results of this study suggest when concrete structures such as bridges or roads expose to the environmental conditions, appropriate measures such as increasing the designed standard strength of concrete need to be deliberated and additional studies should be conducted.

Keywords: chloride-based deicing agent, freezing and thawing, complex durability.

Introduction

In recent years, abnormal weather phenomena have been occurring all over the world. The increase in precipitation in winter has resulted in the heavy use of deicing salt in South Korea. During winter, a lot of deicing agent are sprayed on the roads in order to prevent traffic congestion and safety accidents when the snow falls, or the temperature drops under 0 °C. However, it is known that a large amount of deicing agent on concrete roads causes scaling and peeling on road pavement surface like concrete near ocean, even though they are inland. In addition, the use of chloride-containing deicing agent deteriorates the degradation of performance with the repeated freeze-thaw cycles in winter. In practice, roads and structures using a general performance concrete are constructed without considering the complex effects of the use of the deicing salt with freeze-thaw cycles. Thus, damage to concrete deteriorates the concrete durability reducing its economic advantages due to the shortened service life. In addition, the damage of the concrete pavement causes traffic accidents resulting in fatalities.

In order to prevent deterioration of concrete structures caused by chloride-based deicing agent, studies have been conducted on low-concentration chloride-based deicing agent and eco-friendly deicing agent, suggesting measures to reduce the deterioration of concrete [2].

As concrete structures are exposed to more diverse environment, the performance standards for concrete have been stipulated by various organizations so as to ensure a certain level of performance. In the case of Expressway Construction Guide Specification of South Korea [3], various specified concrete strengths (21 to 45 MPa) are suggested according to the type of structure. The standard specification for concrete [4] and concrete structure design code of South Korea [5], water - binder ratio is specified as maximum 45% and minimum design reference specified concrete strength is 30 MPa for concrete exposed to freeze - thaw or deicing chemical in wet condition.

This study evaluated the durability of concrete subjected concurrently to chloride-induced corrosion and freezing damage according to the calcium chloride concentration using a high-strength concrete mixture and concrete suggested in domestic and international specification regulations.

Material and Methods

The physical properties and the chemical composition of the ordinary portland cement are shown in Table 1. The deicing agent uses the calcium chloride specified in ASTM C 672 [6] and the chemical composition and properties are shown in Table 2. The aqueous solution of calcium chloride was prepared at 4 and 12% used in the test.

The concrete selected in this study was designed to be 24 MPa, 35 MPa, 60 MPa. Detailed concrete formulations are shown in Table 3. The slump and air content are shown in Fig. 1. The slump is 100 ± 20 mm and the air content is 4.5 ± 1.5%. Compressive strength

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Table 1. Chemical composition and physical properties of ordinary Portland cement.

Chemical composition (%)		Physical properties	
SiO_2	22.74		
Al_2O_3	5.7	Density (g/cm^3)	3.14
Fe_2O_3	3.5		
CaO	63.1		
MgO	2.8	Fineness(cm^2/g)	2 800
SO_3	2.2		

Table 2. Quality Specification of the calcium chloride.

TYPE	Unit (%)
$CaCl_2$	74
Nacl	5
Fe_2O_3	0.003
Free acid and Free alkali	0.2

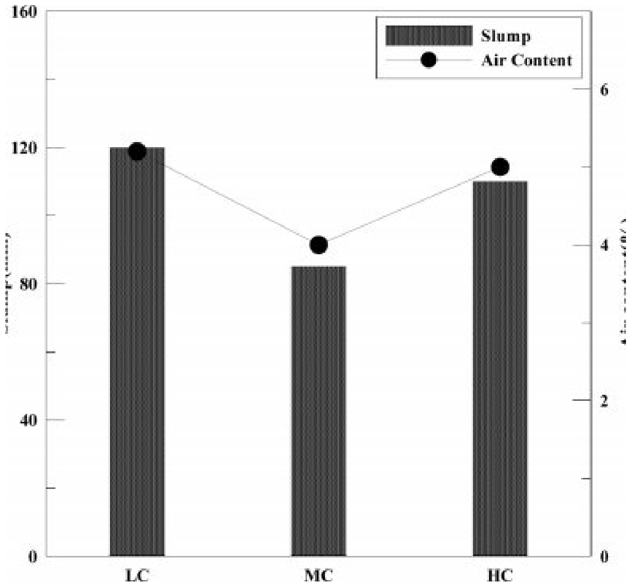

Fig. 1. Slump and air content.

and tensile strength were measured at 28 days, and the results are shown in Fig. 2. As shown in Fig. 2, the compressive strength at 28 days is close to the target compounding strength. Also, the flexural strength was about 17% of the compressive strength. The compressive strength and the flexural strength were measured according to the method described in ASTM C 192 [7], and the compressive strength was measured according to ASTM C 39 [8] after curing in water at 20 ± 2 °C for a period of time. The tensile strength was measured according to ASTM C 1583 [9], and after the completion of the freezing-thaw resistance and scaling resistance test, a 50 × 100 mm core specimen was taken and its compressive strength was examined. In order to investigate the freezing and thawing resistance of calcium chloride deicing agent environment, 4, 12% aqueous solution of calcium chloride was used as frozen water. The test method was examined by the A TYPE test method of

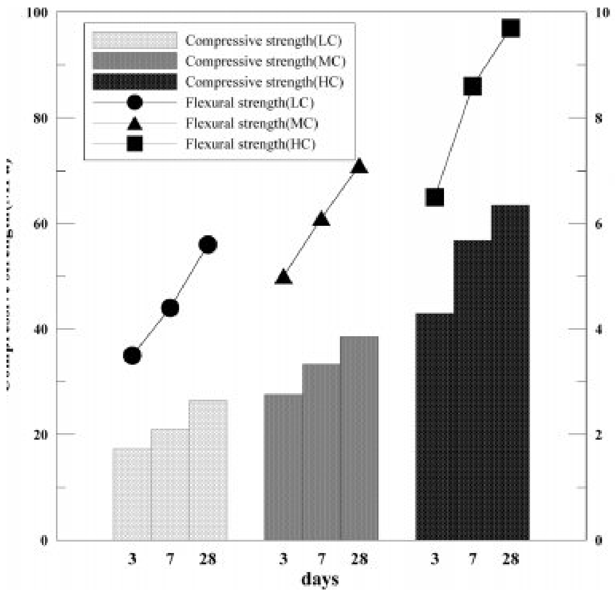

Fig. 2. Compressive and flexural strength.

ASTM C 666 [10], and the relative dynamic modulus of elasticity was measured for every 30 cycles, from -18 °C to -4 °C. The scaling represented by the deterioration phenomenon of the concrete surface in the repeated environment of salting, freezing and thawing was studied. For this study, the amount of scaling was confirmed every 30 cycles using 0, 4 and 12% aqueous solution of calcium chloride as freezing water according to the test method of ASTM C 672, and the freezing and thawing repeated temperature was determined by A type test method of ASTM C 666.

Finally, to evaluate the penetration resistance of the ions, NT Build 492 [11] was used as a test method of accelerated chloride penetration as the chloride ion diffusion coefficient of concrete at the age of 28 day was compared.

Results and Discussion

The freezing-thawing resistance is shown in Figs. 3 to 5. As shown in Fig. 3 to 5, the LC displayed the lowest relative dynamic elastic modulus ratio. The experiment using an aqueous solution of 4% calcium chloride concentration to simulate a deicing agent had the lowest relative dynamic elastic modulus as compared to experiments that used ordinary water or an aqueous solution with calcium chloride concentration of 12%.

Relative dynamic modulus elastic ratio is different depending on the level of compressive strength. In detail, 59% lower for LC and 40% lower for MC using the aqueous solution with the calcium chloride concentration of 4%, It was confirmed that the relative dynamic modulus ratio was decreased to less than 10% in all specimens for HC, this is confirmed that the performance deterioration due to freezing and thawing was not relatively large.

Table 3. Mix design

TYPE	G_{max} (mm)	Slump (mm)	Air (%)	W/C (%)	S/a (%)	Unit content(kg/m^3)				AD (g/m^3)	AE (g/m^3)
						W	C	S	G		
LC	25	80-100	3-6	57.0	49.3	183.9	324.0	860.1	877.7	648.0	19.4
MC				45.0	47.2	167.0	371.0	825.7	916.6	1113.0	33.4
HC				28.0	43.0	144.2	515.0	726.5	955.6	3605.0	108.2

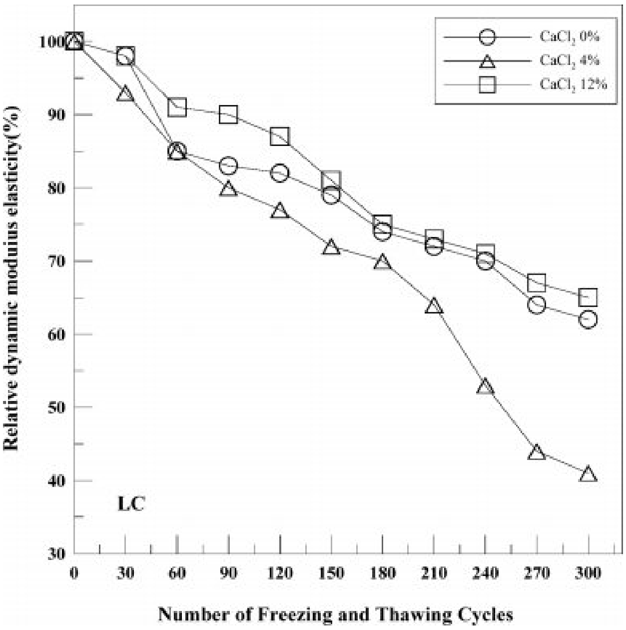

Fig. 3. Relative dynamic elastic modulus LC.

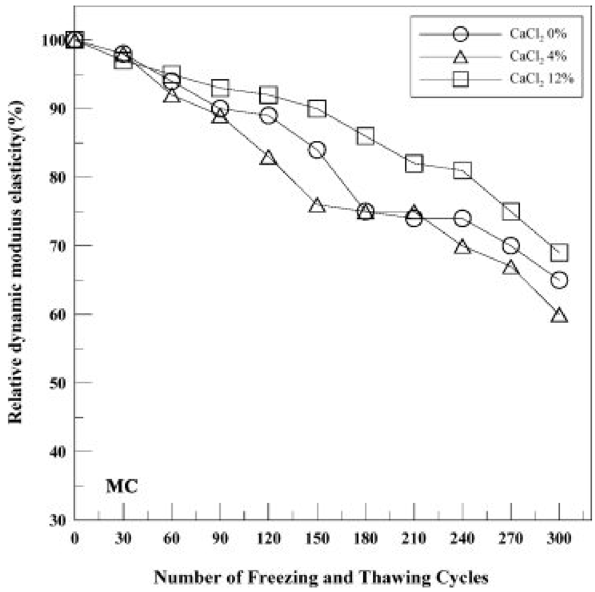

Fig. 4. Relative dynamic elastic modulus of MC.

As the compressive strength increases, the resistance to freezing and thawing was relatively high because the amount of internal surplus water decreased when concrete was frozen because the water-cement ratio of concrete decreased.

Another reason is that as the compressive strength increases, the internal structure becomes dense. The pressure due to the expansion of the freezing water is insignificant. In addition, it was difficult to penetrate the aqueous solution of calcium chloride due to the closed matrix of the concrete inside. Therefore, it is considered that the complex deterioration effect of the freezing and thawing repetition, and salt corrosion on concrete was not significant.

The experiment using an aqueous solution of 4% calcium chloride concentration to simulate a deicing agent had the lowest relative dynamic elastic modulus as compared to experiments that used ordinary water or an aqueous solution with calcium chloride concentration of 12%. The cause of such results may be because the 4% calcium chloride concentration has a higher freezing temperature than its 12% counterpart, leading to more active repetition of freezing and thawing [12]. When freezing water is used as the water without using calcium chloride, the freezing temperature is higher than that of using the deicing agent, but the durability

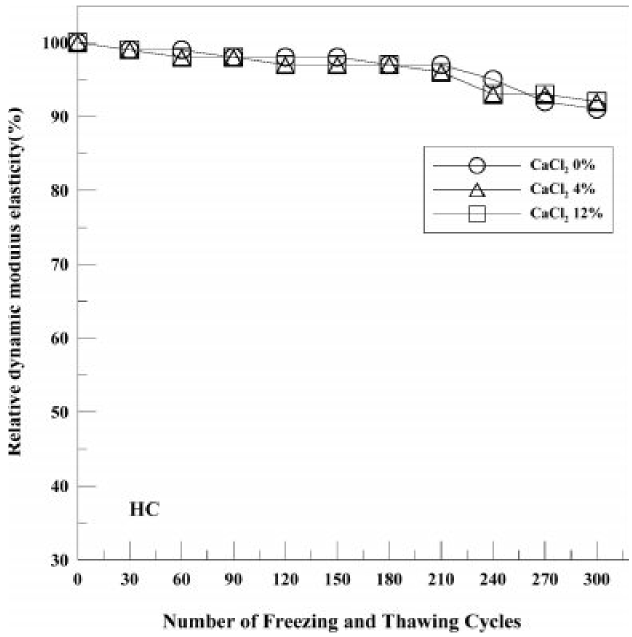

Fig. 5. Relative dynamic elastic modulus of HC.

of the concrete was not deteriorated as much as exposed to the deicing salt.

Therefore, when freezing water is used as the water with using calcium chloride, it is considered that the ratio of relative dynamic modulus of elastic was

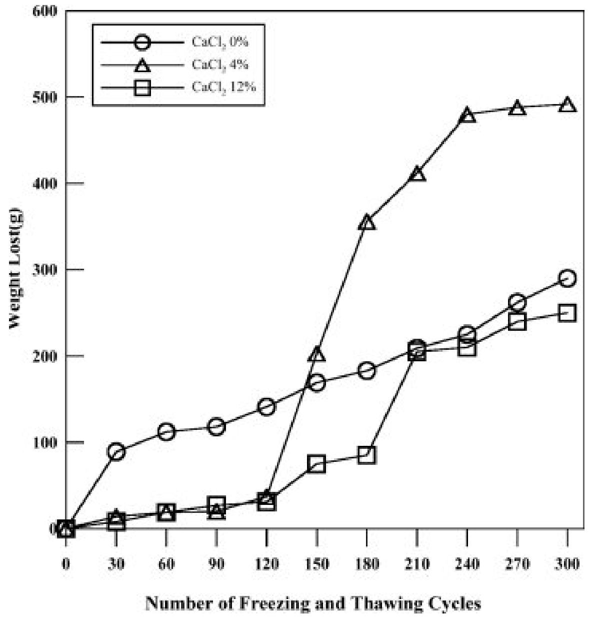

Fig. 6. Scaling of LC.

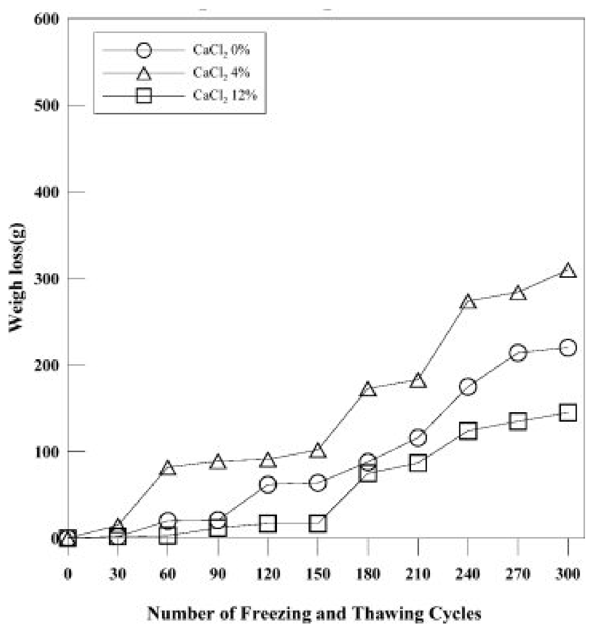

Fig. 7. Scaling of MC.

drastically reduced as the performance of concrete was deteriorated by the combined effects of freeze-thawing and deicing salt damage.

Figs. 6 to 8 show the scaling amount of concrete specimens measured every 30 cycles of freeze-thaw cycles. As shown in the figures, LC and MC showed that the most scaling occurred when using an aqueous solution with a calcium chloride concentration of 4%. It was confirmed that the HC, which is a high strength concrete, remarkably reduces the amount of scaling compared to LC and MC. Concrete with low water - cement ratio or high strength showed little effect on scaling.

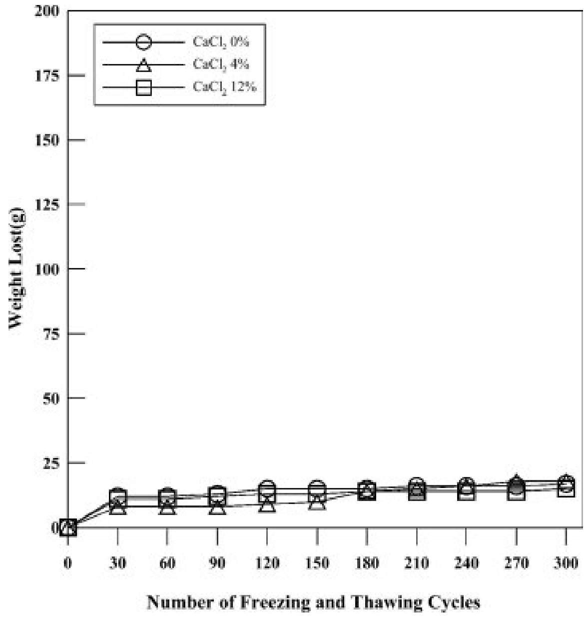

Fig. 8. Scaling of HC.

As a result of the concentration of aqueous solution of calcium chloride, the amount of scaling was large in the case of using 4% aqueous solution of calcium chloride as the freezing water, and the decrease in strength was greatest at the end of the scaling test 46% for LC, and 13% for the high strength concrete HC. The reason for this result is that the freezing temperature of 4% aqueous solution was higher than the freezing water of 12% of calcium chloride as in the results of the freezing and thawing resistance tests [13]. As shown in Fig. 6, when the 4% aqueous solution of calcium chloride was used as the freezing water, rapid scaling was observed between 120 and 150 cycles of freezing and thawing. It is considered that the scaling was accelerated as the deterioration of the concrete performance was accelerated by the complex effect of repeated freeze-thaw cycles and the salt damage. Compared to LC the rapid deterioration phenomenon was not observed in the case of MC. However, the scaling tendency was the same as that of LC when the calcium chloride 4% aqueous solution.

Fig. 9 shows the compressive strengths of all specimens after accelerated scaling. The average compressive strengths of the specimens were 38% for LC, 25% for MC and 12% for HC lowered. It demonstrates that when the deterioration caused by freezing and thawing and scaling continues for a long time, it would be difficult to secure the stability of the concrete structure.

In this study, chloride ion diffusion test was performed to evaluate chloride penetration resistance and watertightness of ions and the durability of concrete by comparing with scaling amount. As shown in Fig. 9, the chloride ion diffusion coefficient and the scaling amount decreased rapidly with increasing compressive strength, such as the chloride ion diffusion coefficient

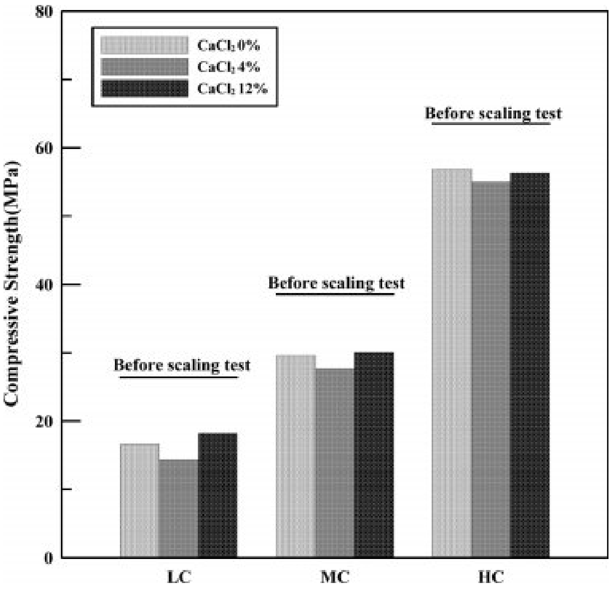

Fig. 9. Compressive strength after scaling 300 cycle.

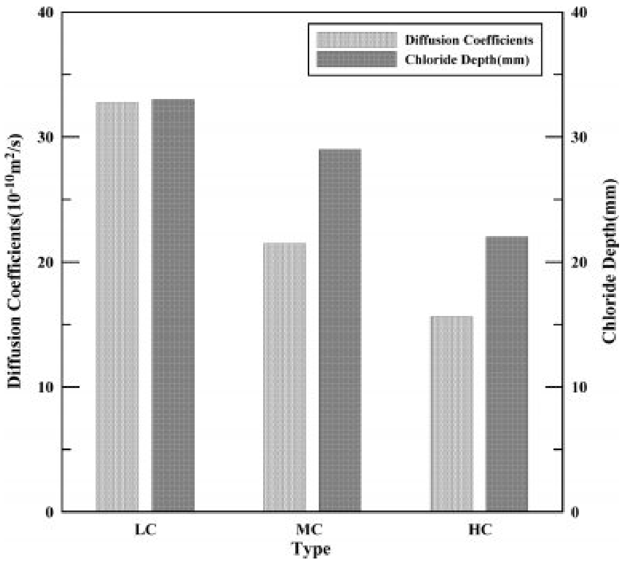

Fig. 10. Chloride ion diffusion coefficients.

of 28 days and the scaling amount measured after 300 cycles. The results may be due to the water-cement ratio is high and the compressive strength is low, the concrete are not densified, and the amount of pores distributed in the microstructure is large, so that the chloride ions are easily diffused into the concrete, It is judged that the deterioration due to scaling is increased.

Summary and Conclusions

In this study, to investigate the durability degradation of concrete in environmental conditions that simultaneously receives salting and freezing and thawing, compressive strength of concrete was classified into three types. Concrete performance deterioration by calcium chloride deicing agent concentration was investigated and the following conclusions were obtained.

1. In the freezing and thawing resistance experiment conducted using an aqueous calcium chloride solution as the deicing solution, performance loss was the greatest when the percentage of calcium chloride in aqueous solution was 4%. Compressive Strength of 24 and 35 MPa Concrete showed a significant decrease in performance due to the freeze-thawing and salt-smoothing effects. In the case of high-strength concrete with a compressive strength of 60 MPa, the concrete strength was increased by maintaining the relative dynamic modulus of 90%. It was confirmed that this method is effective for ensuring durability.
2. As a result of the resistance to scaling, it was confirmed that the scaling amount was the largest when using 4% aqueous solution of calcium chloride as freezing water in all cases of LC, MC and HC. However, in the case of LC and MC, which are ordinary concrete, the degradation of performance due to scaling is large and the performance degradation due to scaling is relatively small in HC as a high-strength concrete.
3. As a result of measuring the compressive strength of the core specimens collected from the scaling test after 300 cycles of repeated exposure, the strength was lower when 4% aqueous solution of calcium chloride was used as the freezing water compared to water without calcium chloride or aqueous solution with calcium chloride concentration of 12%. It was confirmed that the strength was significantly lowered as compared with the case where 4% calcium chloride solution was used as freezing water.
4. The relationship between the chloride ion diffusion coefficient and the scaling amount of the concrete was examined and it was confirmed that the scaling amount was increased with the concrete having a high chloride ion diffusion coefficient. As the diffusion coefficient of chlorine ion decreased and the compressive strength increased, the decrease in the scale amount was larger, and it was judged that the strength enhancement was effective in securing durability against freezing and thawing and salting.

Acknowledgements

This work was supported by the Korea Institute of Energy Technology Evaluation and Planning(KETEP) and the Ministry of Trade, Industry & Energy(MOTIE) of the Republic of Korea (No. 20131020102300).

References

1. K.-B. Lee and S.-W. Lee, J. Korean Soc. Civ. Eng. 27[1D] (2007) 73-80.
2. B.-D. Lee, B.-S. Yun, J.-K. Lee, and Y.-H. Chung, Int. J. Highw. Eng. 7[4] (2005) 113-123.
3. Expressway Construction Guide Specification of Korea

(Korea Expressway Corporation Press, 2012).
4. Standard Specification for Concrete of Korea (Korea Concrete Institute Press, 2009).
5. Concrete Structure Design Code of Korea (Korea Concrete Institute Press ,2012).
6. ASTM Standard, No. ASTM C 672 (2012).
7. ASTM Standard, No. ASTM C 192 (2019).
8. ASTM Standard, No. ASTM C 39 (2018).
9. ASTM Standard, No. ASTM C 1583 (2013).
10. ASTM Standard, No. ASTM C 666 (2015).
11. Nord test, NT BUILD 492 (1999).
12. degradation Research Committee report of concrete structures due to snow melting (Japan Concrete Institute Press, 1999).
13. Marchand. J, Pigeon. M, Bager. D, and Talbot. C, ACI Mater J. 96[4] (1999) 429-435.