

The Technical Development of Using Impregnating Alkalization Agent to Recover Durability of Carbonated Reinforcement Concrete Structures by Fire Damages

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Abstract

Fires breaking out in carbonated reinforcement concrete structures considerably deteriorates the durability of them by propelling carbonation. However, the research and technical development to recover the durability is still in an inadequate stage in Korea.

Therefore, this research aims at understanding the deteriorated durability of a carbonated structure, evaluating the performance of an impregnating alkalization agent to recover the durability and developing a way of using it.

1. Introduction

It is a well-known fact that a carbonated reinforcement concrete structure falls into lower-ed performance due to environments with its age. Carbonation, one of the major factors, is caused by the penetration of CO₂ from the air and acid rain. A strong alkali structure reaching pH 12~13 at its placement loses its alkali to fall to pH 8.5~10 due to such factors. Once the carbonation which began at the surface slowly

progresses into the reinforcement, the passive surface of the bars is destroyed, the corrosion of the reinforcement starts, and the deteriorations of durability such as cracks and spalling of cover concrete due to the corrosion of the reinforcement are caused.

Especially, a fire outbreak in a carbonated reinforcement concrete structure looses the organism by the different contraction and expansion of hardened cement pastes and frames, and causes cracks by thermal stress, leading to the deterioration of the durability. Additionally, if calcium hydroxide pyrolyzes at 500~580°C, the chemical damage of alkalinity

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loss resulting in carbonation happens, also leading to the considerable deterioration of the durability.¹⁾

Lately, the researches on the carbonating mechanism of a carbonated reinforcement concrete structure and the technology of repairing and reinforcing a carbonated structure are flourishing. In foreign countries, re-alkalization, desalinization and electrical methods including the application of chemicals on a carbonated structure in electro-chemical ways are already in practical use.^{2),3)}

However, systematic researches on the carbonation and the deterioration of durability caused by fire in a carbonated reinforcement concrete structure have not reached such a satisfactory stage.

Therefore, this research aims at understanding the deteriorated durability of a carbonated structure, evaluating the performance of an alkalinization agent to recover the durability, and developing a way of using it.

2. Experimental Deterioration of a Carbonated Reinforcement Concrete Structure by Fire Damages

2.1. Deterioration of a carbonated reinforcement concrete structure by fire damages

- ① Chemical properties of the aggregates and hydrates in the concrete change.
- ② Internal pressure increases due to the expansion of free water in the capillary space in the concrete.

③ Cracks are caused by the constriction of the cement paste and the expansion of the aggregate in the concrete.

④ Adhesive strength decreases because of the different expansion of the concrete and the bars causing the increase of confined stress.

⑤ Internal thermal stress increases because of the difference of thermal speed in the concrete.

⑥ Deflection of slab slabs or beams increases due to the decrease of static modulus of elasticity.

2.2 Deterioration of a reinforcement concrete structure by carbonation

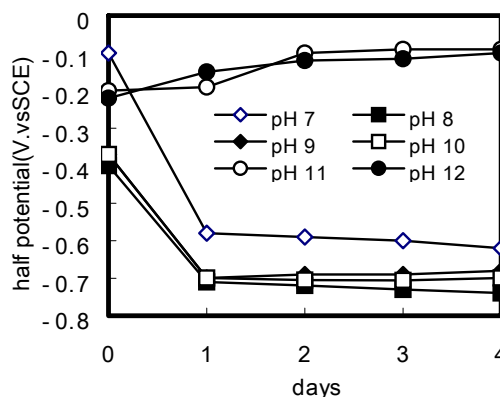


Fig. 1. The relationship between the natural electricity of bars and pH.

The first to be heeded among the factors causing the deterioration of a reinforcement concrete structure by carbonation is the erosion of

Table. 1 Plans for experiment

W/C (%)	compressive strength for 28 days(kgf/cm ²)	application of alkalinization agent(g/m ²)	recovery condition	evaluating method	conditions to propel carbonation
35	565	standard :400±20	outdoor exposure	depth of carbonation photography ICP analysis	40°C of temperature 50% of humidity 15% of CO ₂ density
		surplus :791			
45	435	standard :400±20			
		surplus :861			
55	301	standard :400±20			
		surplus :1076			

bars. If concrete stays at pH 12.4~13.0, it can be said to be in safety, but by carbonation (pH : below 10), erosion accelerates. Fig. 1 points out the relation between pH and the erosion of bars. Below pH 10, bars are eroded quickly, but above pH 12, they are hardly eroded.⁴⁾

3. Technical Development of using impregnating Alkalization Agent to Check Carbonation

3.1 Experiment plans

The experiment plans of this research, as shown in table. 1 aim at evaluating the recovery of alkalinity by the application of impregnating alkalization agent on concrete. To that end, water-cement ratio is divided into three degrees, 35%, 45%, and 55%, and alkalization agent will be applied at a standard 400g/m² and over, and the proportionate re-recovery of alkalinity is evaluated by photo-graphs and ICP analysis according to the material age at exposure surroundings.

3.2 Used materials

Table 2 shows the physical properties of each material, ordinary portland cement is used as the major cement, river sand of 2.57 specific gravity as fine aggregate, crushed pebbles of 2.57 specific gravity as

Table. 2 Physical properties of materials used in this research

cement	O.P.C, fineness : 3,200cm ² /g specific gravity : 3.15,
fine aggregate	river sand, diameter : 2.5mm, specific gravity : 2.57
coarse aggregate	crushed pebbles, diameter : 20mm, specific gravity : 2.57
high performance water reducer	naphthalene, specific gravity : 1.09±0.02

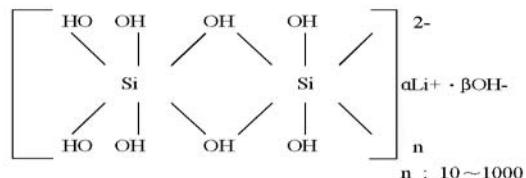
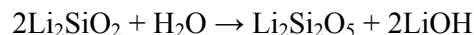


Fig. 2. Chemical structure of Li₂SiO₃

coarse aggregate, and naphthalene was used as high range water reducing agent. Furthermore, the impregnating alkalization agent to recover the alkalinity of a agent to recover the alkalinity of a carbonated specimen was, as shown in table. 3, was a high alkali liquid of pH 11±0.5 mainly consisting of lithium silicate(Li₂SiO₃). The formula of the production of lithium hydrate and silica solidity through the reaction of the impregnating alkalization agent and water is as follows.



In addition, the structure of liquid lithium silicate (Li₂OxSiO₂aq) appears in the form of polysilicate as in fig 2. The diameter of a polysilicate is about 2~20µm, bigger than ion, but much smaller than colloid. Its viscosity is as low as 10CPS, enabling easier penetration into concrete and mortar.⁵⁾

In mixing concrete, we first did dry mixing for one minute by inputting cement, fine and coarse aggregates altogether with a 100ℓ forced pan type mixer, and then mixed another one and a half minute adding water and high performance AE water reducer and then turned out what we want.

The specimen for experimenting recovery of carbonation was a cylinder of ø10×20cm. It went under a 4 weeks standard curing after the day of placement and accelerated carbonation for 6 weeks under 15% of CO₂, 40°C of temperature and 50% of humidity.

After the carbonation acceleration, the cylindrical specimen was splitted into two types according to its running direction. The surface of each was grounded and applied $400 \pm 20 \text{g/m}^2$ of impregnating alkalization agent and it received more agent until it can't absorb any more. It was applied cement paste for finishing. The flow of this experiment is shown in fig. 3.

Table 4. Mixing of Concrete

W/C (%)	S/a (%)	Unit weight(kg/m^3)			
		water	cement	fine aggregate	coarse aggregate
35	42.0	170	486	694	967
45	42.0	170	378	731	1019
55	42.0	170	309	757	1051

3.5 Testing method

In order to measure the depth of carbonation, we divided the specimen to a regular size and sprinkled 1% phenolph-

thalein on the surface, and measured the distance to the point where it wasn't painted red. After measuring the surface was coated with epoxy to be protected from sunlight.

In addition, to analyze the penetrated

Table 3. Physical properties of alkalization agent

ingredient	pH	viscosity	freezing point	specific gravity	color
K_2SiO_3	11 ± 0.5	10CPS	0°C	1.09 ± 0.02	brown

capacity of Li^+ (the main ingredient of impregnating alkalization agent) more quantitatively, we performed ICP(Induced Coupled Plasma) analysis.

3.6 Test results and analysis

demolding	water curing	test of carbonation	alkalization agent+paste	outdoor exposure
1 day	4 weeks	6 weeks	-	52 weeks

Fig. 3. The flow of the experiment.

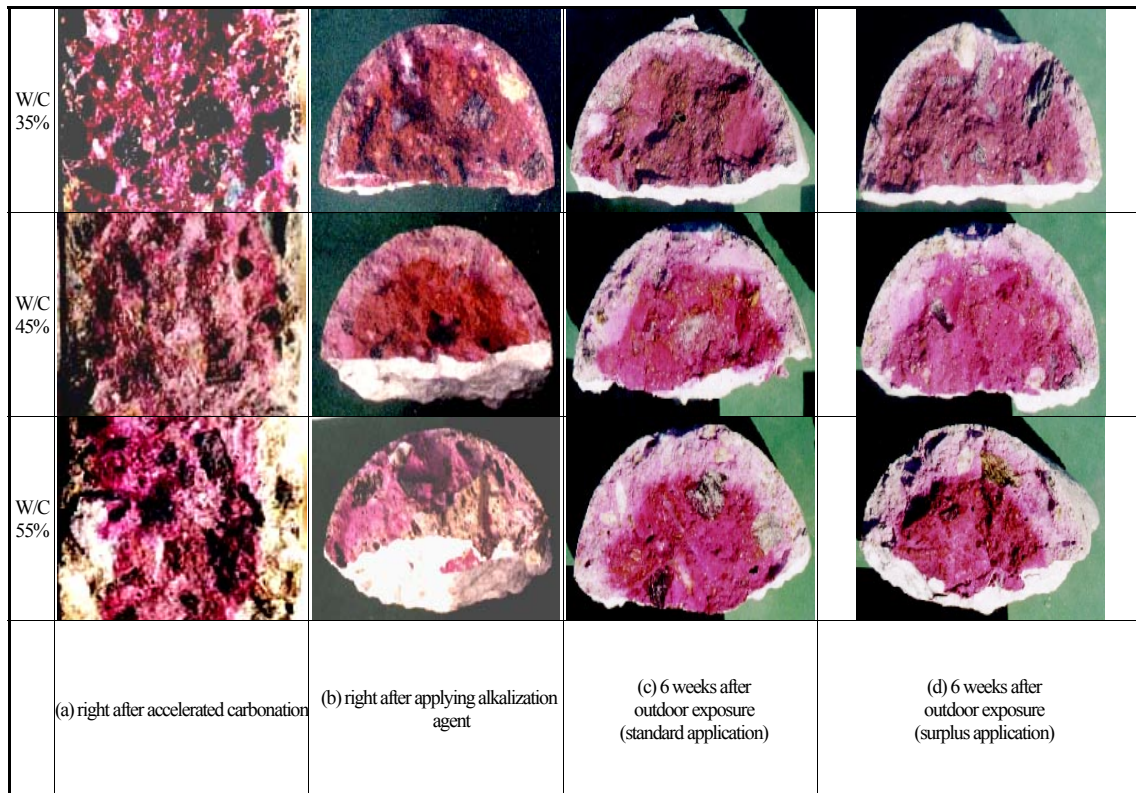


Photo 1. Recovery situation of alkalinity according to applying alkalization agent

1) Evaluation by alcohol method

Photo. 1 shows the depth of carbonation before applying impregnating alkalization agent, its recovery situation right after applying impregnating alkalization agent, and that for 6 weeks when exposed outdoors in three cases according to water cement ratio.

The depth of carbonation before applying impregnating alkalization agent was 7.7mm, 12.7mm, and 15.3mm for each, proportionate with water cement ratio. However, after applying standard impregnating alkalization agent, we saw them all recovering alkalinity through their painted surfaces.

On the other hand, the recovery of specimens exposed outdoors for 6 weeks after being applied standard or surplus impregnating alkalization agent was rather indistinct than right after the application, impregnating alkalization agent was rather indistinct than right after the application, but in all cases they all showed constant alkalinity by their painted surfaces. But the recovery or maintenance of alkalinity in these cases was hard for a naked eye to evaluate through alcohol method

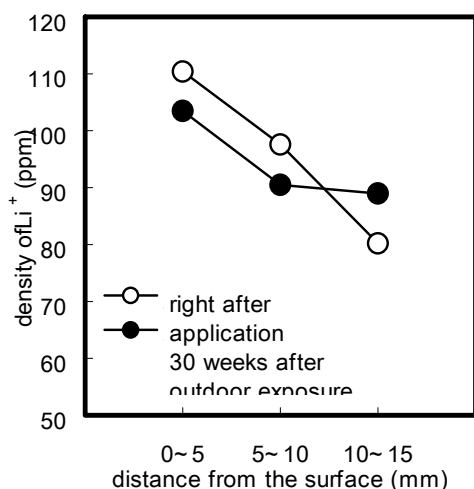


Fig. 4 Li⁺ density according to the depth

2) Results of ingredient analysis

For a more quantitative evaluation of the penetration of impregnating alkalization agent, we pointed out the result of ICP analysis of Li⁺ (the main ingredient of impregnating alkalization agent) after its application in fig. 4.

The density of Li⁺ right after application according to the depth was highest at the surface, measured 110.4 ppm at 0~5 mm, 97.6 ppm at 5~10 mm, and 80.2 ppm at 10~15 mm, and it is considered to have reached more than 15 mm in depth.

After 30 weeks of outdoor exposure, they showed 103.5 ppm, 90.5 ppm, and 89 ppm of penetration similar to those of the moment of application, promising practical effectiveness when applied on a actual structure.

4. Practical Example of Applying Rehabilitation Technology on a Carbonated Reinforcement Concrete Structure by Fire Damage

4.1. The history and deteriorated situation of a structure

The structure repaired and reinforced in this research was overpass in district, metropolitan city. Table. 5 shows its history and surroundings and table. 6 shows its deteriorated situated and the analysis of causes, and subsequent plans for repair construction.

This structure has suffered a serious degree of carbonation from 2 cases of fire and increasing density of carbon monoxide due to the use of briquettes for heating. Inflows of rainfalls and snow removing materials add to its water leakage, efflorescence, heaving, and corrosion of bars.

Table. 5 The history and surroundings of ○○○overpass

category	time of completion	age	structure	maintenance	total traffic	surroundings
contents	1970. 12	27 years	Mixture of RC slab beam(3 section) and PC slab beam(3 section)	blueprint and construction drawing missing Insufficient maintenance	30,000 cars on the average	.100~200 houses of 1 or 2 stories under the slab until 1996 .Railroad under the section made of PC girder .Two fire outbreaks by 1997

Table. 6 Analysis of the conditions and causes of heating and ways to repair and reinforce

category	deterioration	causes of deterioration	ways to repair and reinforce
top ascon	<input type="checkbox"/> cracks at expansion joint	<input type="checkbox"/> overlay in ignorance of expansion joint <input type="checkbox"/> meteorological factors such as changes of seasons or temperature	<input type="checkbox"/> re-pavement after removing ascon <input type="checkbox"/> installation of expansion joint
slab top bottom	<input type="checkbox"/> spalling around joints <input type="checkbox"/> splits of concrete layers <input type="checkbox"/> serious corrosion of bars, efflorescence, heaving and spalling around joints and drainage <input type="checkbox"/> cracks at several parts	<input type="checkbox"/> inflows of rainfalls through cracks of expansion joint <input type="checkbox"/> cold joints at the time of construction <input type="checkbox"/> cracks at expansion joint <input type="checkbox"/> clogged drainage <input type="checkbox"/> inflows chloride of snow removing chemicals <input type="checkbox"/> use of briquettes for heating, acceleration of carbonation through fire <input type="checkbox"/> increase in traffic	<input type="checkbox"/> waterproofing of concrete surface <input type="checkbox"/> rehabilitation of heaving and spalling part <input type="checkbox"/> reinstallation of drainage <input type="checkbox"/> control corrosion of bars <input type="checkbox"/> recovery from carbonation (re-alkalization) <input type="checkbox"/> rehabilitation of heaving and spalling part <input type="checkbox"/> rehabilitation of cracks through U cutting
beam RC PC	<input type="checkbox"/> efflorescence and leakage of free lime <input type="checkbox"/> strong possibility of corrosion of bars <input type="checkbox"/> flexural cracks under beams	<input type="checkbox"/> segregation of concrete (bottom) <input type="checkbox"/> use of briquettes for heating, acceleration of carbonation through fire <input type="checkbox"/> increase of load due to increase in traffic	<input type="checkbox"/> recovery from carbonation (re-alkalization) <input type="checkbox"/> control corrosion of bars <input type="checkbox"/> increase of bearing capacity (attaching carbon fiber) <input type="checkbox"/> recovery from carbonation (re-alkalization) <input type="checkbox"/> increase of bearing capacity (install PC reinforcement wire)
column	<input type="checkbox"/> heaving of concrete <input type="checkbox"/> exposure of bars	<input type="checkbox"/> insufficient thickness of surface <input type="checkbox"/> use of briquets for heating, acceleration of carbonation through fire	<input type="checkbox"/> control corrosion of bars <input type="checkbox"/> recovery from carbonation (re-alkalization) <input type="checkbox"/> rehabilitation of heaving and spalling part

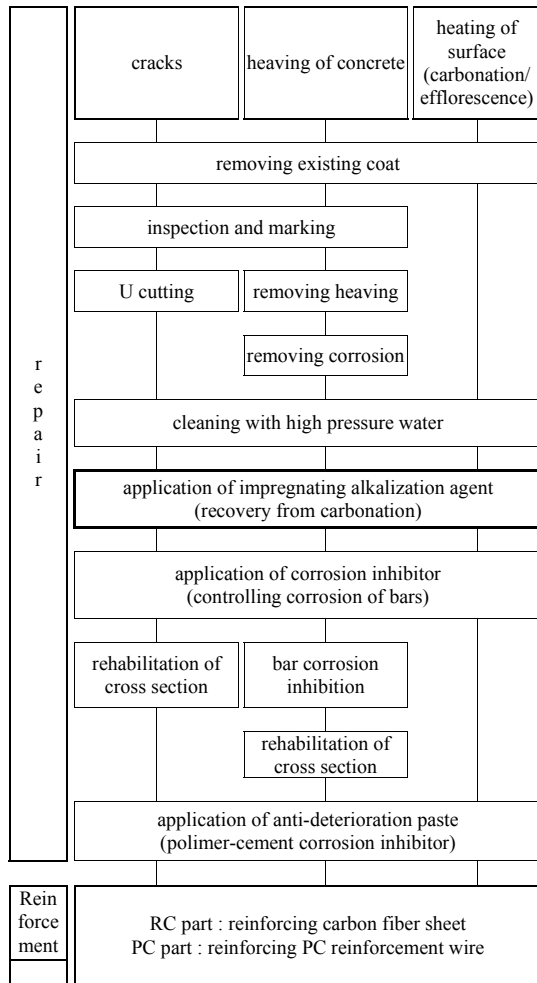


Fig. 5 Flow of repair construction

4.2 Repair construction to recover the durability of a carbonated reinforcement concrete structure by fire damages

Fig. 5 show the flow of construction according to the deteriorated situation of the structure. especially, impregnating alkalization agent was applied on the parts which carbonation is accelerated after a fire to recover their alkalinity.

On the other hand, for parts suffering or promising corrosion of bars, sprinkling corrosion inhibitor was applied to control corrosion of bars, and for parts missing surfaces, polymer-cement material was used to restore the surface, both to increase durability of concrete.

And, in the cases of beams suffering flexural cracks, two methods were applied to increase their durability by reinforcing with carbon fiber for RC parts and PC steel wire for PC parts.

5. Conclusion

We have come to following conclusions after evaluating the performance of impregnating alkalization agent and applying it on a actual structure to recover the durability of a carbonated reinforcement concrete structure by fire damages.

1) Recovery of alkalinity turned out to be possible after photographs and ICP analyses of alkalinity recovery of a carbonated concrete.

2) Impregnating alkalization agent was applied on an actual structure as a repair technology to recover the durability of a carbonated reinforcement concrete structure by fire damages. And, to utilized this repair technology, a far-sighted evaluation of repair material and technology is required.

Acknowledgment

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