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

화재로 인해 중성화된 철근콘크리트구조물의 내구성 회복을 위한 침투성 알칼리성부여제의 이용기술개발

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요 약

철근콘크리트구조물에서 발생하는 화재는 중성화를 촉진시켜 철근콘크리트구조물의 내구성을 현저하게 저하시키는 원인이 된다. 그러나 국내의 경우 화재로 인해 중성화가 촉진된 철근콘크리트구조물의 내구성 회복을 위한 연구 및 기술개발이 미비한 실정이다. 따라서 본 연구는 화재로 인해 중성화된 철근콘크리트 구조물의 성능저하현상을 파악한 후 내구성 회복을 위하여 침투성 알칼리성부여제의 성능을 평가하고 이용기술을 개발하고자 하였다.

ABSTRACT

Fire 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 underdeveloping stage in Korea. Therefore, this research aims to 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.

Keywords : Durability, Carbonation, Impregnating alkalization agent, Re-alkalization

1. Introduction

It is a well-known fact that a carbonated reinforcement concrete structure falls into lowered performance due to environments with its age. Carbonation, one of the major factors, is caused by the penetration of CO_2 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 reinforce ment, 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 deteriora tion of the durability. Additionally, if calcium hydroxide pyrolyzes at 500~580°C, the chemical damage of alkalinity loss resulting in carbonation happens, also leading to the considerable deteriora tion of the durability.[1)]

Lately, the researches on the carbonating mechanism of a carbonated reinforcement concrete structure and

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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 che mical ways are already in practical use.[2,3)]

However, systematic researches on the carbona tion 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 alkalization agent to recover the durability, and developing a way of using it.

2. Experimental Deterioration Mechanism 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 changes by heat.
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 slaves or beams increases due to the decrease of static modulus of elasticity.

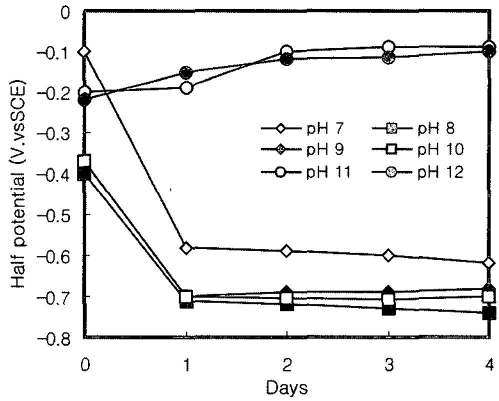

Fig. 1. The relationship between the natural electricity of bars and pH.

2.2 Deterioration of a Reinforcement Concrete Structure by Carbonation

The first to be heeded among the factors causing the deterioration of a reinforcement concrete struc ture by carbonation is the erosion of bars. If conc rete stays at pH 12.4~13.0, it can be said to be in safety, but by carbonation (pH : below 10), ero sion accelerates. Fig. 1 illustrate 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 to evaluate the recovery of alkali nity by the application of impregnating alkalization agent on

Table 1. Plans for experiment

W/C (%)	Compressive strength for 28 days (kgf/cm^2)	Application of alkalization 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			

Table 2. Physical properties of materials used in this research

Materials	Physical properties
Cement	O.P.C, fineness : 3,200 cm^2/g specific gravity : 3.15
Fine aggregate	river sand, diameter : 2.5 mm, specific gravity : 2.57
Coarse aggregate	crushed pebbles, diameter : 20 mm, specific gravity : 2.58
High performance water reducer	naphthalene, specific gravity : 1.09 ± 0.02

Table 3. Physical properties of alkalization agent

Ingredient	pH	Viscosity	Freezing point	Specific gravity	Color
Ki_2SiO_3	11 ± 0.5	10 CPS	0°C	1.09 ± 0.02	brown

concrete. To that end, water-cement ratio was varied as 35%, 45%, and 55%, and alkalization agent was applied at a standard 400 g/m^2 or more, and the proportionate recovery of alkalinity is evaluated by photographs and ICP analysis according to the exposure age at surroundings of specimen.

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 coarse aggregate, and naphthalene was used as high range water reducing agent.

Furthermore, the impregnating alkalization agent to recover the alkalinity of carbonated specimen in Table 3, was a high alkali liquid of pH 11 ± 0.5 mainly consist of lithium silicate (Li_2SiO_3). The formula of the production of lithium hydrate and silica solidity through the reaction of the impregna ting alkalization agent and water is as follows.

$$2Li_2SiO_2 + H_2O \rightarrow Li_2Si_2O_5 + 2LiOH$$

In addition, the structure of liquid lithium silicate ($Li_2O_xSiO_2$ aq.) appears in the form of polysilicate as in Fig. 2. The diameter of a polysilicate is about 2~20 μm, it is bigger than ion, but much smaller than colloid. Its viscosity is as low as 10 CPS, enabling easier penetration into concrete and mortar.[5)]

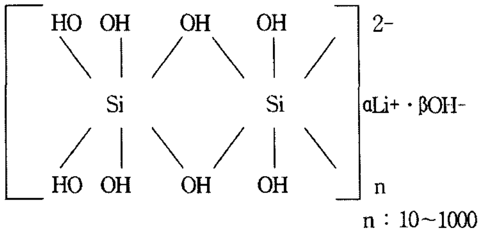

Fig. 2. Chemical structure of Li_2SiO_3.

Table 4. Mixing of Concrete

W/C (%)	S/a (%)	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

3.3 Mixing of Concrete

Table 4 shows the mixing performed in this research. The water content is set at 170 kg/m^3, and water cement ratio was varied into three kind of 35, 45, 55%.

3.4 Mixing Method and Preparation of Specimen

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

The specimen for experiment of recovery of carbonation was a cylinder type of ϕ10 cm × 20 cm. It left 4 weeks for standard curing after the day of placement and accelerated carbonation for 6 weeks under 15% of CO_2, 40°C of temperature and 50% of humidity.

After the carbonation acceleration, the cylindri cal specimen was splitted into two types according to its running direction. flow of this experiment is shown in Fig. 3.

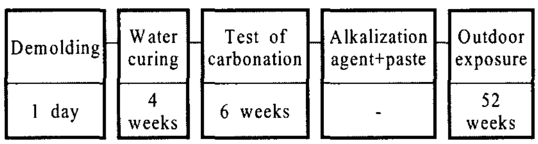

Fig. 3. The flow diagram of the experiment.

3.5 Testing Method

In order to measure the depth of carbonation, we cut and divide the specimen to a regular size and sprinkled 1% phenolphthalein on the surface, and measured the depth. The surface of each specimen was ground and applied $400 \pm 20\ g/m^2$ of impregnating alkalization agent and it received more agent until it can't absorb any more. It was applied cement paste for finishing. The distance to the point where it wasn't colored red. After measuring the surface was coated with epoxy to be protected from sunlight.

In addition, to analyze the penetrated capacity of Li^+(the main ingredient of impregnating alkalization agent) in quantitatively, we performed ICP (Induced Coupled Plasma) analysis.

3.6 Test Results and Analysis

3.6.1 Evaluation by Alcohol Method

Fig. 4 shows the depth of carbonation before applying impregnating alkalization agent, its recovery situation just 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 7.7 mm, 12.7 mm, and 15.3 mm for each, proportionate with water cement ratio. However, after applying standard impregnating alkalization agent, we can find that all of it recovered alkalinity through their colored 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 just after the application, but in all cases all of it showed constant alkalinity by their colored

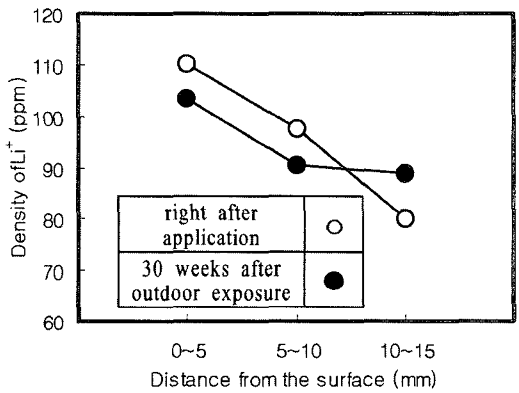

Fig. 5. Li^+ density according to the depth.

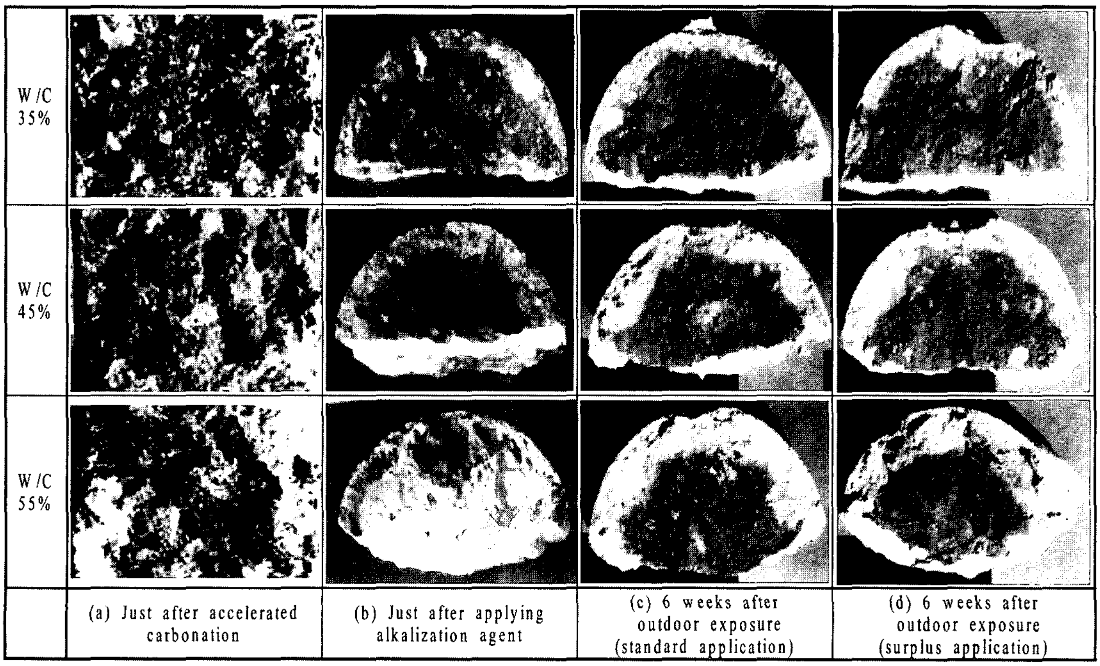

Fig. 4. Photo of recovery situation of alkalinity according to applying alkalization agent.

surfaces. But evaluation of recovery or maintenance of alkalinity through alcohol method by naked eye was difficult.

3.6.2 Results of Ingredient Analysis

For a more quantitative evaluation of the penet ration of impregnating alkalization agent, we shows the result of ICP analysis of Li^+ (the main ingredient of impregnating alkalization agent) after its application in Fig. 5.

The density of Li^+ just after application according to the depth was highest at the surface, as 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 Li^+ 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 Li^+ density similar to those of the moment of application, promising practical effectiveness when applied on a actual structure.

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 Method to repair and reinforce

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

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

A case study of structure repaired and reinforced was done as an example in a metropolitan in Korea. Table 5 shows its history and surroundings and Table 6 shows its deteriorated situation and the analysis of causes, and subsequent plans for repair construction.

This structure has suffered a serious degree of carbonation from 2 times of fireandcarbon monoxide density was increased dueto the use of briquettes for heating. Inflows of rainfalls and calcium chloride for snow removing add to its water leakage, efflorescence, heaving, and corrosion of bars.

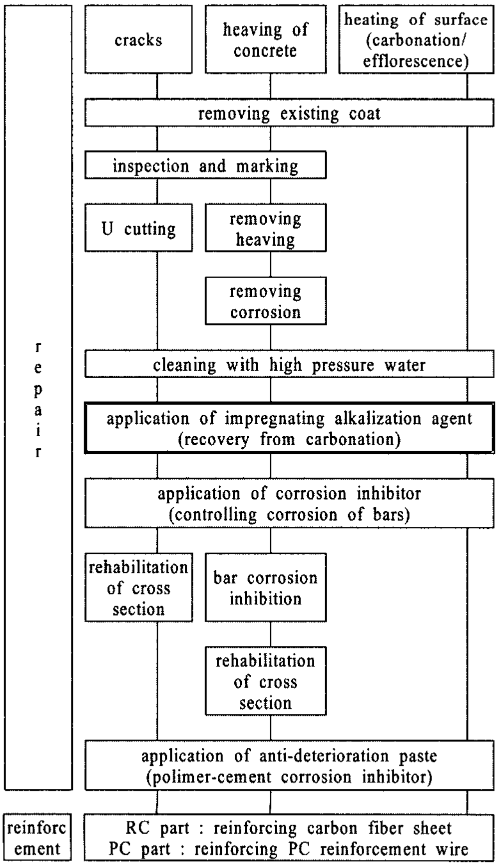

Fig. 6. Flow diagram of repair construction.

4.2 Repair Construction to Recover the Durability of a Carbonated Reinforcement Concrete Structure by Fire Damages

Fig. 6 show the flow diagram of construction according to the deteriorated situation of the structure. Especially, impregnating alkalization agent was applied to 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 corrosioninhibitor 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 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. And Fig. 7. Fig. 8. show the appling method of reinforcing with carbon fiber.

Fig. 7. Photo of appling method of reinforcing with carbon fiber.

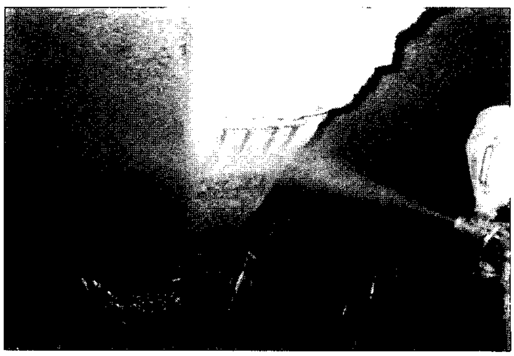

Fig. 8. Photo of appling method of sprinkling with polymer cement material.

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 farsighted evaluation of repair material and technology is required.

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