KCI CONRETE JOURNAL
Vol.14 No.4, Dec., 2002, pp.145-150

Corrosion Protection Method of Reinforcing Steel in Concrete by Using Corrosion Inhibitors

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(Received July 29, 2002; Accepted December 25, 2002)

Abstract

Reinforced concrete is inherently a durable composite material. When properly designed for the environment to be exposed and carefully constructed, reinforced concrete is capable of giving maintenance-free performance. However, unintentionally using improper materials such as non-washed sea sand having much salt together with poor controlled quality, or the concrete are placed in highly severe environment such as marine atmosphere, the corrosion of reinforcing steel in concrete becomes one of the most significant concerns of concrete.

The purpose of this experimental research is to evaluate the performance of corrosion inhibitors for normal strength and high strength concrete, and to propose desirable measures for controlling corrosion of reinforcing steel in concrete. Test specimens in normal strength and high strength concrete were made with and without corrosion inhibitors. The accelerated corrosion test for reinforcing steel in concrete was adopted in accordance with JCI-SC3, which required the periodic 20 cycles for 140 days. One cycle includes 3 days for the wetting condition of 65℃ and 90% RH, and 4 days for the drying condition of 15℃ and 60% RH.

It was observed from the test that corrosion inhibitors in normal strength concrete and high strength concrete showed excellent corrosion resistance for reinforcing steel in concrete, but the silica fume in high strength concrete was found to have a negligible corrosion resistance if not used with corrosion inhibitors, since the chloride corrosion threshold limit in concrete containing silica fume without corrosion inhibitor was found to be considerably smaller than that of the case with corrosion inhibitor.

Keywords: ***reinforced concrete, reinforcing steel, corrosion protection method, corrosion inhibitors, accelerated corrosion test***

1. Introduction

Due to the shortage of river sand which resulted from the rapid growth on the construction of the concrete structures construction in Korea, the usage of sea sand was gradually increased instead. Non-washed sea sands in reinforced concrete structures cause to corrode the reinforcing steel and then incur cracks in concrete. Marine concrete structures are exposed to detrimental chloride environment which causes to accelerate the corrosion of reinforcing steel in concrete. Similarly reinforced concrete bridge decks can be deteriorated due to the deicing calcium chloride in the winter season.

The corrosion of reinforcing steel induced by chloride-penetration into concrete may severely deteriorate concrete structures. Thus, development of pertinent corrosion protection methods for reinforced concrete structures exposed to severe chloride environment is strongly needed.

There are various corrosion protection measures[1-8)] for reinforcing steel in concrete, such as good-quality concrete, thick cover concrete, epoxy coated reinforcing steel, corrosion inhibitors used as concrete admixtures, appropriate cathodic protection systems, etc. Recently, corrosion inhibitors are widely used as one of the most practical methods for the corrosion protection of reinforcing steel in concrete.[9)] The purpose of this experimental research is to evaluate the performance of corrosion inhibitors for the corrosion protection of reinforcing steel in normal strength

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concrete and high strength concrete. Test specimens were manufactured for the accelerated corrosion test for reinforcing steel in normal strength concrete and high strength concrete, and then test had been carried out in cyclic wet and dry conditions on the basis of JCI-SC3[10] for 140 days. Test parameters were water/cement, with and without corrosion inhibitors, NaCl content, etc.

2. Experimental program

2.1 Materials

Ordinary portland cement (KS L 5201, Type 1) was used in the study. The physical properties of the cement are shown in Table 1. River sand and crushed stone of 20mm maximum size were used as fine aggregate and coarse aggregate, respectively, their physical properties are shown Tables 2 and 3. In order to carry out the accelerated corrosion test for reinforcing steel in concrete, D13 deformed steel bars with yield strength of about 340MPa were used. A corrosion inhibitor was adopted to investigate its performance for the corrosion resistance of reinforcing steel in concrete. The quality properties of the corrosion inhibitor are shown Table 4. Superplasticizer(SP) including sodium salt of a sulfonate naphthalene was also used in the study, its quality properties are shown Table 5. Silica fume in a specific gravity of 2.2 and a fineness of 20,000㎡/kg was used to investigate its performance of corrosion protection for reinforcing steel in concrete. And, salt concentration in concrete was controlled by using 96% pure sodium chloride

2.2 Mix proportion

Table 6 shows the mix proportions for normal strength and high strength concrete specimens, which used the water/cement(W/C) ratio as 50.5% and 32%, and the target slump as 150±20mm and 210±20mm, respectively. To investigate the influence of corrosion inhibitor for the corrosion protection of reinforcing steel in concrete, normal strength concrete specimens with 50.5% W/C ratio were made by limiting the salt concentration with 0.1%, 0.2% and 0.5% by weight of fine aggregate, which were mixed with and without corrosion inhibitor. High strength concrete specimens with and without silica fume(SF) were also made to investigate the influence of silica fume on the performance of corrosion protection for reinforcing steel in concrete[11]. 32 % W/C ratio and similar contents of salt concentrations were used in high strength concrete specimens.

In addition, concrete cylinders with and without corrosion inhibitor were produced in order to examine the influence of corrosion inhibitor on the compressive strength of concrete.

Table 1 Physical properties of cement

Specific gravity	Setting time (min)		Fineness (㎠/g)	Compressive strength (kgf/㎠)		
	Initial	Final		f_3	f_7	f_{28}
3.12	150	330	3,465	194	245	308

Table 2 Physical properties of fine aggregate

Fine Aggregate	Specific gravity	Absorption (%)	Unit weight (ton/㎥)
River sand (Nakdong-river)	2.60	1.08	1.597
Fine aggregate	Weight of passing No. 200 sieve(%)		F.M.
River sand (Nakdong-river)	2.2		2.92

Table 3 Physical properties of coarse aggregate

Coarse aggregate	Gmax (mm)	Specific gravity	Absorption (%)
Crushed stone (Anodng)	20	2.65	0.6
Coarse aggregate	Unit weight (ton/㎥)	F.M.	Abrasion (%)
Crushed stone (Anodng)	1.648	6.57	28.5

Table 4 Quality properties of corrosion inhibitor

ASTM type	Specific gravity	pH	Quantity (ℓ/㎥)
C 494 Type C	1.3	8~10	10~30
ASTM type	Solid content (%)		Freezing point (℃)
C 494 Type C	32~36		-15

Table 5 Quality properties of chemical admixture

Specific gravity	Solid content (%)	pH	Quantity(%) (by weight of cement)
1.21	41	8	0.2~2.0
Main component		Remarks	
Sodium salt of a sulfonate naphthalene		Liquid	

2.3 Test specimens

Geometric detail of test specimen is shown in Fig.1. Two deformed reinforcing steels were placed vertically at the base of $\phi 100 \times 200$mm cylinder using foaming polystyrene spacer. $\phi 100 \times 200$mm concrete cylinders were made for the investigation of compressive strength. Test specimens for the accelerated corrosion test were placed at the normal temperature of about 20℃ under the vinyl cover for 7 days before the start of the accelerated corrosion test. Also, test specimens for compressive strength test were cured in the water of 20±3℃ during the specified ages.

2.4 Accelerated corrosion test

In this accelerated corrosion test, the periodic cycles of wet and dry conditions in accordance with JCI-SC3 were adopted for concrete test specimen. During the wetting period under 65℃ and 90% RH, water as electrolyte could be penetrated into cover concrete and corrosion could be accelerated under high temperature. During the drying period under 15℃ and 60% RH, on the other hand, oxygen could be also supplied because of the drying environment even though thick water layer, formulated in the previous wet

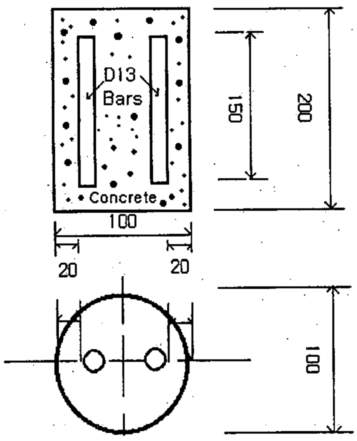

Fig. 1 Test specimen (Measurements in mm)

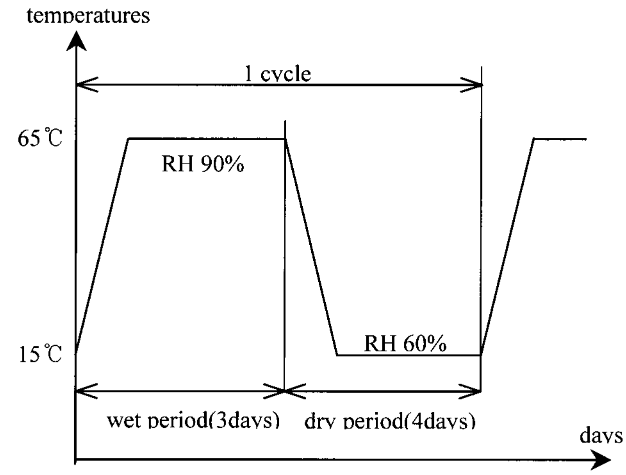

Fig. 2 Condition of accelerated corrosion test

Table 6 Mix proportions of normal and high strength concrete

Type of concrete		NaCl (%)	C.I* (ℓ/m³)	Slump (mm)	Target air content (%)	W/C (%)	S/a** (%)	Unit weight (kg/m³) Water	OPC+	SF	Sand	Gravel	SP++ (%)
OPC concrete	Normal strength concrete (NSC)	0.1	0+++	170	3.0±0.5	50.5	41	182	360	0	728	1,040	0.7
			10+++	158									1.0
		0.2	0	165									0.8
			10	157									1.0
		0.5	0	160									0.7
			10	158									1.0
	High strength concrete (HSC)	0.1	0+++	200	3.0±0.5	32	37	176	550	0	621	1,004	1.4
			10+++	185									1.9
		0.2	0	191									1.4
			10	190									1.9
		0.5	0	195									1.4
			10	190									1.9
Concrete with SF (SFC)		0.1	0+++	185	3.0±0.5	32	37	176	495	55	614	992	1.8
			10+++	190									2.2
		0.2	0	190									1.8
			10	190									2.2
		0.5	0	208									1.8
			10	190									2.2

* Corrosion inhibitor
** Absolute fine aggregate ratio
\+ Ordinary portland cement
++ Superplasticizer by weight of (OPC+SF)
+++ Mix proportions to investigate strengths of concrete with and without corrosion inhibitors

condition, might inhibit the oxygen to reach at the surface of reinforcing steel in concrete. This testing procedure is considered to simulate actual corrosion process of reinforcing steel in reinforced concrete structures. Fig. 2 shows the process of the accelerated corrosion test for reinforcing steel in concrete test specimens. In this test, testing cycles were carried out up to 20 cycles. According to KS F 2405, in addition, compressive strength of test cylinders at 3, 7, 28 and 91 days through elapsed time were carried out.

3. Result and discussion

3.1 Effect of corrosion inhibitor on steel corrosion

3.1.1 Ordinary portland cement(OPC) concrete

1) Normal strength concrete(NSC)

Fig. 3 and 4 show corroded reinforcing steel drawing after breaking test the specimen. Amount of the corroded rebar was measured by the rate of corroded surface area to total surface area of reinforcing steel.

Fig. 5 shows the results of the accelerating corrosion test for reinforcing steel in normal strength concrete specimens. The corroded surface areas of reinforcing steel in concrete without corrosion inhibitor(C.I) were found to be magnified by increasing the salt concentration. Any corroded surface area of reinforcing steel was not found in concrete test specimens with corrosion inhibitor if included less 0.1% salt concentration by weight of fine aggregate. But for test specimens above 0.2% salt concentration by weight, the corroded surface areas were found to be significantly reduced with the aid of corrosion inhibitor, comparing with those of corresponding specimens without corrosion inhibitor. It can be concluded that the corrosion inhibitor seems to be an effective method for practical corrosion protection of reinforcing steel in concrete structures.

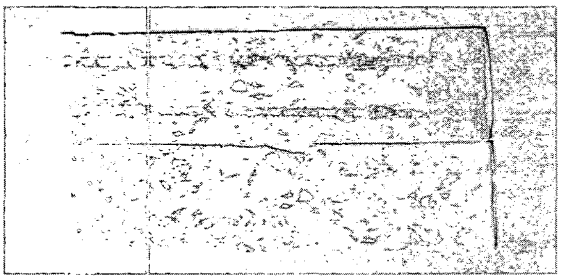

Fig. 3 Corroded reinforcing steels in concrete

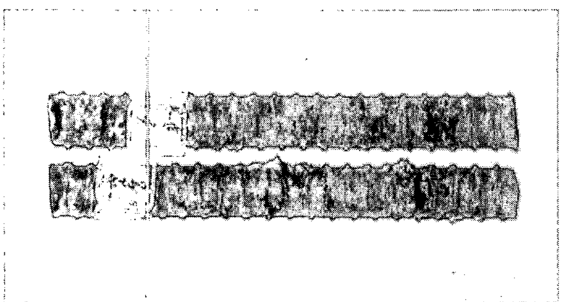

Fig. 4 Corroded reinforcing steels

2) High strength concrete(HSC)

Fig. 6 shows the results of accelerating test for high strength concrete specimens. In similar to NSC, any corroded surface area of reinforcing steel was not found in concrete test specimens with corrosion inhibitor if included less 0.2% salt concentration by weight. But for test specimens with 0.5% salt concentration by weight, the corroded surface area of all test specimens were found to be significantly decreased with the aid of corrosion inhibitor, comparing with those of corresponding specimens without corrosion inhibitor.

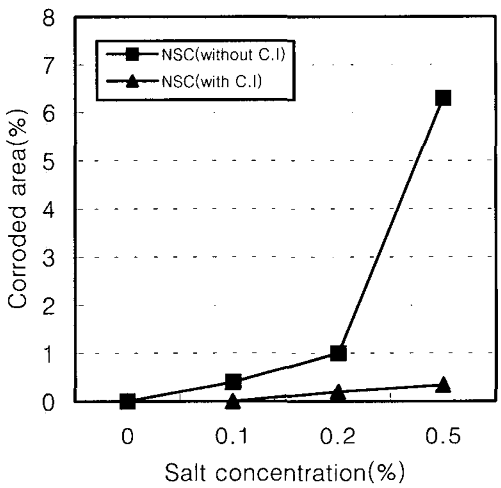

Fig. 5 Corroded surface area of reinforcing steel for normal strength concrete

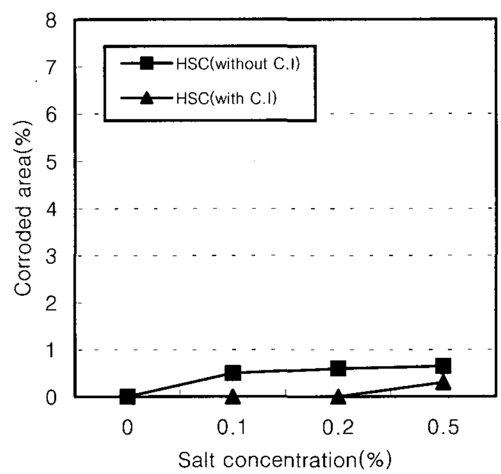

Fig. 6 Corroded surface area of reinforcing steel for high strength concrete

For all test specimens with and without corrosion inhibitor, meanwhile, it could be said that the corroded surface areas of reinforcing steel in high strength concrete specimens were in general very small, comparing with those for normal strength concrete. It seems that in the case of high strength concrete, its dense microstructure might make permeations of oxygen and water difficult at the surface of rebar in concrete.

On the other hand, it is in particular noted for high strength concrete specimens without corrosion inhibitor that the corrosion of reinforcing steel was initiated at 0.1% salt concentration by weight of fine aggregate. It could be concluded that even high strength concrete could not increase chloride corrosion threshold limit if not used with corrosion inhibitor.

3.1.2 Concrete with silica fume(SFC)

Fig. 7 shows the results of the accelerated corrosion test for concrete with silica fume(SFC). As shown in Fig. 7, it was observed that the corroded surface areas of reinforcing steel in concrete with silica fume were found to be similar to those of high strength concrete without silica fume. On the other hand, silica fume in SFC without corrosion inhibitor could not contribute to resist the corrosion of reinforcing steel.

Therefore, it was thought that only strength improvement of concrete could not be the effective corrosion protection measures for reinforcing steel in concrete, since the corroded areas of reinforcing steel in high strength concrete without corrosion inhibitor were found to be considerably wider than those of high strength concrete with corrosion inhibitor.

3.2 Effect of corrosion inhibitor on compressive strength of concrete

Fig. 8 shows compressive strength results of normal strength and high strength concrete with ordinary portland cement(OPC). It was found from the test of normal strength concrete(NSC) that compressive strengths of NSC with corrosion inhibitors are a little bigger than those of NSC without corrosion inhibitors. But it was observed that there were negligible differences between compressive strengths of HSC with and without corrosion inhibitors.

Fig. 9 shows compressive strength results of concrete containing silica fume(SFC) with and without corrosion inhibitors. It was found that irrespective of addition of corrosion inhibitors the compressive strengths of SFC are similar to those of high strength concrete without silica fume. Thus, the effects of corrosion inhibitor used in the study on compressive strength of concrete could be ignored.

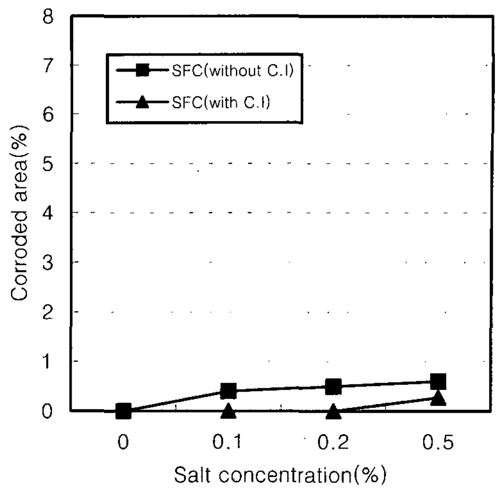

Fig. 7 Corroded surface area of reinforcing steel for concrete containing silica fume

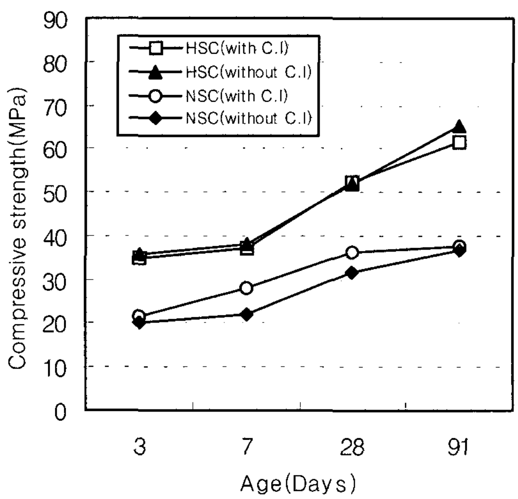

Fig. 8 Compressive strength of OPC concrete

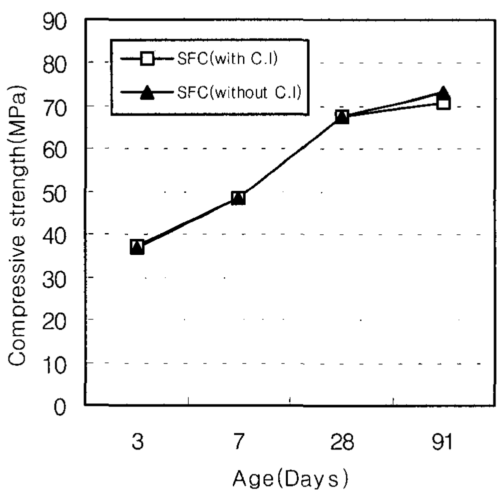

Fig. 9 Compressive strength of concrete containing silica fume

4. Conclusions

The effects of corrosion inhibitor for corrosion protection of reinforcing steel were studied for ordinary strength and high strength concrete test specimens with variable water/cement, salt content, silica fume, etc. It can be concluded from the test results that:

1) The corroded surface area of reinforcing steel with corrosion inhibitor were not found in normal strength test specimens of not more than 0.1% salt concentration by weight of fine aggregate. But for test specimens with 0.2% and 0.5% of salt concentration by weight, the corroded surface areas were found to be significantly reduced with the aid of the corrosion inhibitor.
2) The corroded surface area of reinforcing steel with corrosion inhibitor were not found in high strength test specimens of not more than 0.2% salt concentration by weight. But for test specimens with 0.5% salt concentration by weight, like normal strength test specimens , the corroded surface areas were found to be significantly decreased with the aid of the corrosion inhibitor.
3) It was noted from high strength concrete without corrosion inhibitor that the effect of silica fume on corrosion protection of reinforcing steel was found to be negligible. Thus, it was thought that use of high strength concrete with corrosion inhibitor could be an effective corrosion protection measures for reinforcing steel in concrete.
4) It was revealed that the compressive strength of the concrete with corrosion inhibitor was almost equivalent to the non-corrosion inhibitor concrete irrespective of the level of compressive strength and with and without silica fume.

Acknowledgement

This research was partially supported by the Korea Research Institute of Standards and Science under Grant No. 98-ND-03-04-A-01. This support is gratefully acknowledged.

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