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PROBABILITY FOR CARBONATE STRESS CORROSION CRACKING IN REBARS AND PC RODS IN THE CARBONATE CONCRETE

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ABSTRACT

Rebars in bridge piers suffer from serious damages by ASR. And also, there is some case that PC rods in PC pole show sudden break. These fractures might be occurred by the stress corrosion cracking. Many studies point out that these fractures are caused by hydrogen embrittlement. Our consideration is that concrete of these structures have been carbonated, and rebars and PC rods are occurred by carbonate stress corrosion cracking. This study is revealed experimentally that the stress corrosion cracking is happened on rebars and PC rods in the carbonated concrete.

In case of the experiment using rebars with tensile strength 550N/mm^2 and bended into U shape, the possibility of carbonate stress corrosion cracking is predicted by Parkins's method, in which the rebars are exposed in the solutions with $0.5\text{mol/L K}_2\text{CO}_3 - 1.0\text{mol/L NaHCO}_3$ or $0.5\text{mol/L K}_2\text{CO}_3 - 1.5\text{mol/L NaHCO}_3$ at 353K temperature. Then, the electric potential of the rebar in $0.5\text{mol/L}-1.0\text{mol/L}$ solutions is kept in 660mV vs SCE, while the potential in $0.5\text{mol/L}-1.5\text{mol/L}$ solutions is kept in 670mV . On the rebars in both solutions, stress corrosion cracks appear. It is revealed that the rebars are susceptible to carbonate stress corrosion cracking.

In the case using PC rod with tensile strength 1529N/mm^2 , and bended in U shape, the rods are exposed in the solution with $0.5\text{mol/L K}_2\text{CO}_3-1.0\text{mol/L NaHCO}_3-1.0\text{g/L Ca(OH)}_2$ at room temperature, and the potential is not controlled. Stress corrosion cracking also appears on the rod, and it is clear that PC rods have high sensitivity to carbonate stress corrosion cracking.

Both the type of steel and the exposure condition must be considered to investigate occurrence of stress corrosion cracking on steel. In this study, it is clear that both rebars and PC rods have high possibility to occur carbonate stress corrosion cracking in the carbonated concrete.

Keywords: Carbonate Stress Corrosion Cracking, Rebars, PC Rods

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1. INTRODUCTION

In some cases of bridge piers suffering from serious damages caused by ASR, or of PC pole, a few breaks of reinforcing steel bars (here-in-after called “rebars”) or PC rods are happened. These fractures might be occurred by the stress corrosion cracking. Many studies point out that these fractures are caused by hydrogen embrittlement (e.g.Hanada 2009). However as in considerable sum of these structures, concrete have been carbonated, the rebars and PC rods might break due to occur carbonate stress corrosion cracking. In this study, possibility of carbonate stress corrosion cracking on rebars and PC rods in the carbonated concrete are examined experimentally.

2. CARBONATE STRESS CORROSION CRACKING IN REBARS

2.1. Experimental method

Rebars with D13(SD295A) of which mechanical characteristics is shown in Table 1, are used as test specimens. After ribs on the center area of the rebar are removed and a V-shape notch is put at the area, the rebar is bent into 180 degrees. Then, the U-shape rebar is fixed by the blanket. Experimental equipment is shown in Figure 1. The specimens are exposed in a solution with 0.5mol/L K_2CO_3 - 1.0mol/L $NaHCO_3$ at 353K temperature or in the one with 0.5mol/L K_2CO_3 - 1.5mol/L $NaHCO_3$ at 353K temperature, respectively, then, the electric potential of each specimen is controlled in the one where carbonate stress corrosion cracking considerably occurs. The controlled value of the potential is decided based on the results of polarization curve measured in advance. The scanning rate of polarization curves is 0.2mV/sec. A saturated calomel electrode (SCE) is used as the reference electrode.

Table 1:Mechanical characteristics

	0.2%proof stress ($N \cdot mm^2$)	Elastic modulus ($10^5 N/mm^2$)	Tensile strength ($N \cdot mm^2$)
Rebars	368	1.88	550

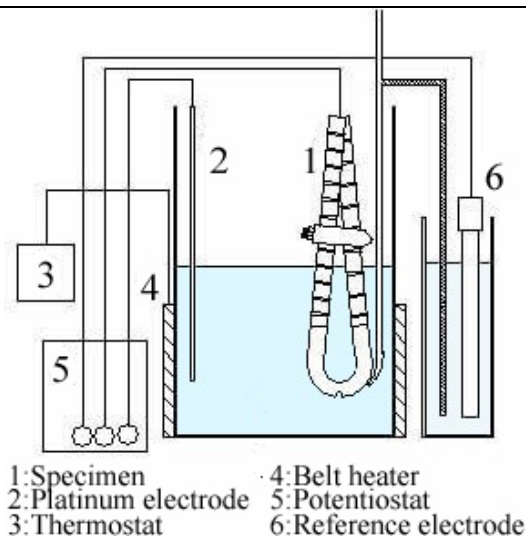


Figure 1: Experimental equipment

2.2. Results

2.2.1 Polarization curve

The potential range of carbonate stress corrosion cracking is consistent with the one at which current density changed extreme in polarization curve(Parkins:1972). Therefore, it can be predicted by a measurement result of polarization curve. From the results of the polarization curve shown in Figure 2, the potentials which are predicted by the polarization curve are 660mV (vs SCE) for 0.5mol/L-1.0mol/L solutions and 670 mV (vs SCE) for 0.5mol/L, respectively. These potential are used to stress corrosion cracking test.

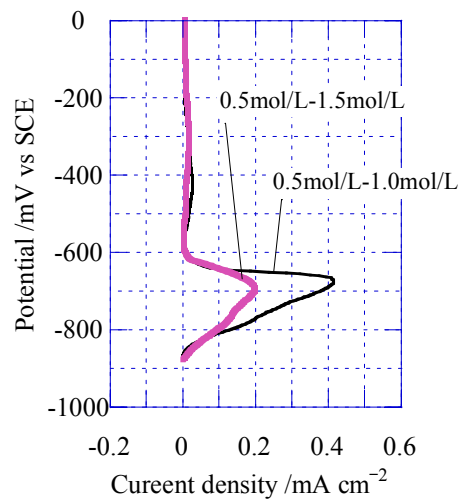


Figure 2: Polarization curves

2.2.2 Immersion test at controlled potential

As an example, the cracking condition on the specimen exposed in 0.5mol/L-1.0mol/L solutions is shown in Photo 1. One the specimens exposed in 0.5mol/L-1.0mol/L solutions and 0.5mol/-1.5mol/L solutions, the stress corrosion cracks arise after 190 hours and 200 hours, respectively, from an examination start.

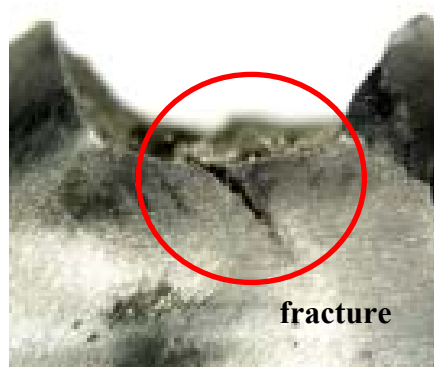


Photo 1: The fracture of specimen exposed 0.5mol/L-1.0mol/L solutions

3. CARBONATE STRESS CORROSION CRACKING IN PC RODS

3.1. Experimental method

PC rod is used as the specimens, and its mechanical characteristics are shown in Table 2. After ribs on the center area of the rod are removed and a V-shape notch is put at the area, the rod is bent into 180 degrees. Then, the U-shape rod is fixed by the blanket. Experimental equipment is shown in Figure 3. The specimens are exposed in a solution with 0.5mol/L K_2CO_3 -1.0mol/L $NaHCO_3$ -1.0g/L $Ca(OH)_2$ at room temperature, immediately after they are exposed in 10% H_2SO_4 solution at 5 minutes in order to remove oxide film of the specimen. In the experiment, the electric potential of specimens is not controlled but the natural potential is measured by using saturated calomel reference electrode.

Table 2: Mechanical characteristics

	0.2% proof stress ($N \cdot mm^{-2}$)	Elastic modulus ($10^5 N/mm^2$)	Tensile strength ($N \cdot mm^{-2}$)
PC rods	1448	2.23	1529

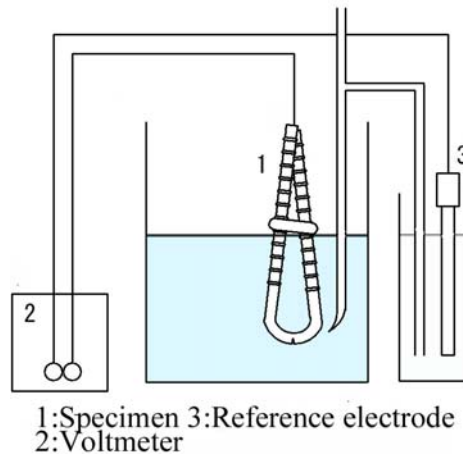


Figure 3: Experimental equipment

3.2. Results

Photo 2 shows the fracture condition of PC rod specimen. A stress corrosion cracking occurs on the specimen after 16 hours from the examination start. Figure 4 shows change of the natural



Photo 2: The fracture of PC rod

potential of the specimen with test period. After the specimen was exposed during 14 hours, the natural potential has changed to positive direction quickly. Such the potential changed seems to be related to stress corrosion cracking.

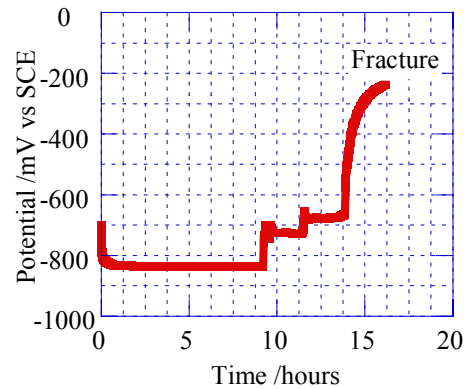


Figure 4: Natural potential of the specimen to the failure

4. Discussion

The concentration of Na^+ and K^+ in pore solution of the mortar is about 0.66mol/L respectively, when the mortar is made with cement having the high alkali concentration (Ono 1986). On the other hand, the concentration of Na^+ and K^+ in the solutions used in the experiment is 1.5mol/L and 2.0mol/L of which concentration is 2.3 times and 3.0 times higher than that of pore solutions. Furthermore, the concentration may increase 6 to 9 times when the electrical current flows in to concrete due to reinforcement corrosion (Kuroi 1989 and Pages 1992). Therefore, it is thought that the alkali concentration of the solutions used in the experiments can simulate the environment corresponded at the concrete carbonated really when a macro-galvanic cell is created on steel reinforcements in the carbonated concrete. Therefore, the results of the experiment seems to show the high passivity that carbonate stress corrosion cracking are happened on rebars and PC rods subjected constantly tensile stress in the carbonated concrete.

5. CONCLUSIONS

Rebars and PC rods were examined in stress corrosion cracking. It can be clear that rebars and PC rods have carbonate stress corrosion cracking susceptibility when rebars and PC rods subjected constantly tensile stress in the carbonated concrete.

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