NEW CATHODIC PROTECTION SYSTEM FOR CONCRETE STRUCTURES USING NICKEL-COATED CARBON FIBRES SHEET ANODES

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Abstract

Nickel-coated carbon fiber sheet and net were developed as new type of anodes for cathodic protection systems of reinforced concrete structures. Accelerated tests and long term tests on durability of anodes and systems were carried out. Results of accelerated tests showed that provided voltage is not almost increased. It was found that 20mA/m^2 was enough to get cathodic protection effect and Operational life is expected more than 5 years. Results of long term tests showed that instant off potentials of anodes kept below 1V(Ag/AgCl), which means chlorine is not discharge. Consequently, it was confirmed that the new developed anodes not only have high performance but also are cheaper than normal anodes.

1. INTRODUCTION

Carbon materials are widely used for anode of cathodic protection systems. In recent years, these materials are used for concrete structures exposed in the atmosphere. Cathodic protection systems using carbon materials anode are better than conventional systems, such as titanium is used as anode, concerning economy. However, existing systems using carbon materials anode are not durable enough. Because to meet demands we developed a new system using durable carbon fiber sheet. Durability of anodes is drastically progressed by coating with nickel. There are two methods to use the anodes in the cathodic protection system. One is so-called anchoring anode-components. They are fixed on the surface of concrete at a constant interval. The anode-component is composed of FRP-holder, nickel-coated carbon fiber sheet and absorbable polymer. The anode-sheet surrounded by an absorbable polymer with high conductivity and alkalinity is placed in FRP-holder. Another method is surface-mounted anode-net systems embedded in cementations overlay. The anode-nets are fixed on the whole surface of pretreated concrete and embedded in the high alkalify cementations overlay. In order to prove performance of anode applied to concrete structures, four series of tests are carried out. The first one is accelerated tests, which prove durability of carbon fiber sheet(Ni/CFS) anode's, referring to the National Association of Corrosion Engineers (NACE) Test Method(TM0294-94). The second tests are to confirm durability of anode systems. Ni/CFS anodes surrounded by solid electrolyte are installed on mortar blocks with high level of chloride contamination assuming concrete structures in marine environments. The tests are continuing more than 600 days. The third tests are for anode net systems. The fourth tests are performed to improve execution-ability of anchoring anode-components.

2. DURABILITY OF Ni/CFS ANODE'S

2.1Outline

It is easy to coat a carbon with nickel and nickel-plated anodes has advantages of running at high current densities in alkaline electrolytes, obtaining low operating anode oxygen over voltage, and low consumption of itself. In an alkaline solution nickel behaves like high-performance of corrosion resistance. For its high-performance, nickel depends on passivity of Ni(OH)2.It is true that passivity dissolves in a halogen ion solution, but making an addition to a negative ion of OH-, they become reprocessing passivity. Accelerated life testing shall therefore be conducted in an NaOH solution. The accelerated conditions for adding NaCl, to solution, impressed current are 0.2,2,20A/m2 , and 180 days. In NACE Test Method, anodes shall be demonstrated to survive a minimum total charge density of 110 mA/m2 *40 years, equal amount of total charge density of 8,900 mA/m2 * 180 days are operated in concrete simulated pore water, and the passing mark should be recorded when the anode potential increases by 4.0V below its initial value. Experimental sample are Ni/CFS. It is having 20.0cm2 of anode surface area. The power supply are galvanostat (15V,1A).The working electrode(WE) are Ni/CFS.The counter electrode(CE) are titanium electrode and the reference electrode(RE) are a silver/ silver chloride electrode. Figure 1 shows a test cell.

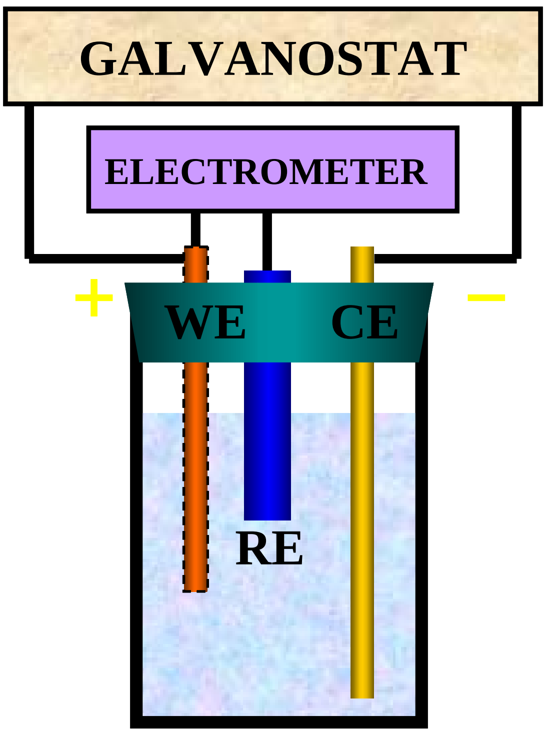

Figure.1: test cell

2.2 RESALT

To accelerate cathodic protection, all the sample are conditioned to impressing current density with 0.2, 2,20mA/m2, immersing in the aqueous solutions with concentration of 0-8 (%)NaOH. and Test continued after 180 days. The results with surface change, duct, and solution change in the aqueous solutions are shown in Table 2. As can be observed in table.2, The Ni/CFS anodes appears to be no change higher than 4%NaOH solutions with impressed current density 0.2,2,2A/m2. And the surface of these samples is well condition. When the samples are tested corrosive conditions with 3%NaCl solutions, however these sample appeared to be corrosion resistance. Maximum total charge densities of this test are 20 mA/m2 of anode surface for 180 days, which are equaled 10A/m2 years. When the current density is 110mA/m2, impressed current of this test is 10A/m2 yeras/110mA/m2=90.9 years. There are change the tone of color with solution to brown and dark brown. The cause of changing the tone of color with solution is assumed by dissolving carbon. The other side, when the aqueous solutions with concentration is less than 4 (%) NaOH, the samples are observed to violently corrosion. Therefore the testing of these samples are discontinued.

Table 2: surface change,educt, solution change

<table>
<tr><td>current</td><td>NaCl(%)</td><td colspan="6">3</td></tr>
<tr><td rowspan="4">20A/m^2</td><td>NaOH(%)</td><td>0</td><td>0.3</td><td>0.5</td><td>2</td><td>4</td><td>8</td></tr>
<tr><td>surface change</td><td colspan="2" rowspan="3">stop</td><td colspan="2">black</td><td colspan="2">no change</td></tr>
<tr><td>educt</td><td>green</td><td colspan="2">brown</td><td>nothing</td></tr>
<tr><td>solution</td><td colspan="2">no change</td><td colspan="2">dark brown</td></tr>
<tr><td rowspan="4">2A/m^2</td><td>NaOH(%)</td><td>0</td><td>0.3</td><td>0.5</td><td>2</td><td>4</td><td>8</td></tr>
<tr><td>surface change</td><td rowspan="3">stop</td><td colspan="3">black</td><td colspan="2">no change</td></tr>
<tr><td>educt</td><td colspan="3">a part of black</td><td colspan="2">nothing</td></tr>
<tr><td>solution</td><td colspan="3">no change</td><td colspan="2">brown</td></tr>
<tr><td rowspan="4">0.2A/m^2</td><td>NaOH(%)</td><td>0</td><td>0.3</td><td>0.5</td><td>2</td><td>4</td><td>8</td></tr>
<tr><td>surface change</td><td colspan="3">a part of light green</td><td>black</td><td colspan="2">no change</td></tr>
<tr><td>educt</td><td colspan="4">a part of black</td><td colspan="2">nothing</td></tr>
<tr><td>solution</td><td colspan="4">no change</td><td colspan="2">brown</td></tr>
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3. DURABILITY OF ANODE SYSTEMS

3.1Outline

A system is required to conduct with ionic between concrete structures and the anode on the concrete surface with surrounded by a solid electrolyte. And so then An solid electrolyte is required to being in environment having enough alkaline to react its passivation and to being no liquefaction and to keep a solution for a long period of time. All experimental sample and mix proportion are prepared from hydraulic material and clayey mineral and super absorbent polymer. The basic electrolysis solutions are determined by first test result in range from 4.0 to 8.0 (%)NaOH solutions relative to the corrosion resistance. and To accelerate positive damage, the impressed current density shall be required to range from 20 to 200 mA/m2.and laboratory blocks exposed for two years to outdoor condition. The parameter is shown in Table.3. Figure.2 shows blocks of mortar. The blocks of mortar are prepared for mix proportion 1:1 sand Portland cement, 110mm long*70mm wide 40mm high, and having a plate of titanium with placed horizontally ,and anode is placed over the surface surrounded by solid electrolyte ,and covered with resinous layer for the purpose of keeping wet, and attached externally to titanium connecter plates. The durability of anode in the conditioning is assessed by measuring driving voltage and anodic instant off potentials of the anode. Driving voltage are measured by an potentials difference between anode and cathode.

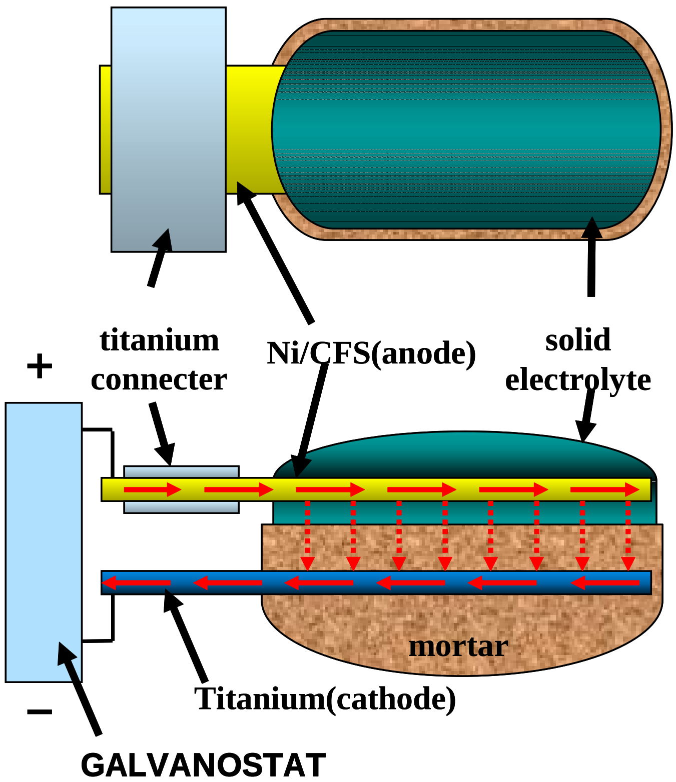

Figure.2:blocks of mortarl

Table.3: The parameter of second test

solid electrolyte		sign	concentration (%)	current density (mA/m^2)
mortar	ordinarily portland cement	OPM	0、4、8	20～200
	expanded mixture portland cement	EPM		
	emulsion polymer portland cement	PPM		
clayey	Bentonite	CMB	8、15	40～200
polymer	super absorbent polymer	SAP		

3.2 RESALT

Figure.3 and 4 represents driving voltages(DV) and anodic instant off potentials of the anode(AIO) of the system impressed anodic current density with 100mA/m2, and solutions with concentration of 8 (%)NaOH, and a temperature of environment. The Driving voltages are examined by comparing five type of solid electrolyte with electrometer. Five type of solid electrolyte are provided for ordinarily Portland cement mortar (OPM), expanded mixture Portland cement mortar (EPM), emulsion polymer Portland cement mortar (PPM), clayey mineral Betonies (CMB), super absorbent polymer (SAP). As can be observed in Figure.3, 4, DV and AIO are depend on a temperature. When the temperature increase, DV and AIO are decrease. Figure.3 shows, PPM are immediately begins to increase after 2 days. CMB are slowly, however, begins to suddenly increase after 200 days. It is found to be a crack in solid electrolyte with CMB, which are deepened in the interface with Ni/CFS. Because, it exposure to outdoor. The other side, it is found to be no change in OPM, EPM, and SAP with DV. Because, these are contained a large amount of water than PPM, and so There are maintain ionic conductors of solid electrolyte, which are enough to electrify them. Figure.4 shows typical AIO values at the different solid electrolyte per blocks during the time that the experiment was conducted. CMB is exceedingly higher in AIO than the type of OPM,EPM,SAP, and after 50days it is increased the difference in values between CMB and the others. SAP is exceedingly less in AIO than 0.5V (Ag/AgCl), which is indicated to be sufficiently corrosion resistance.

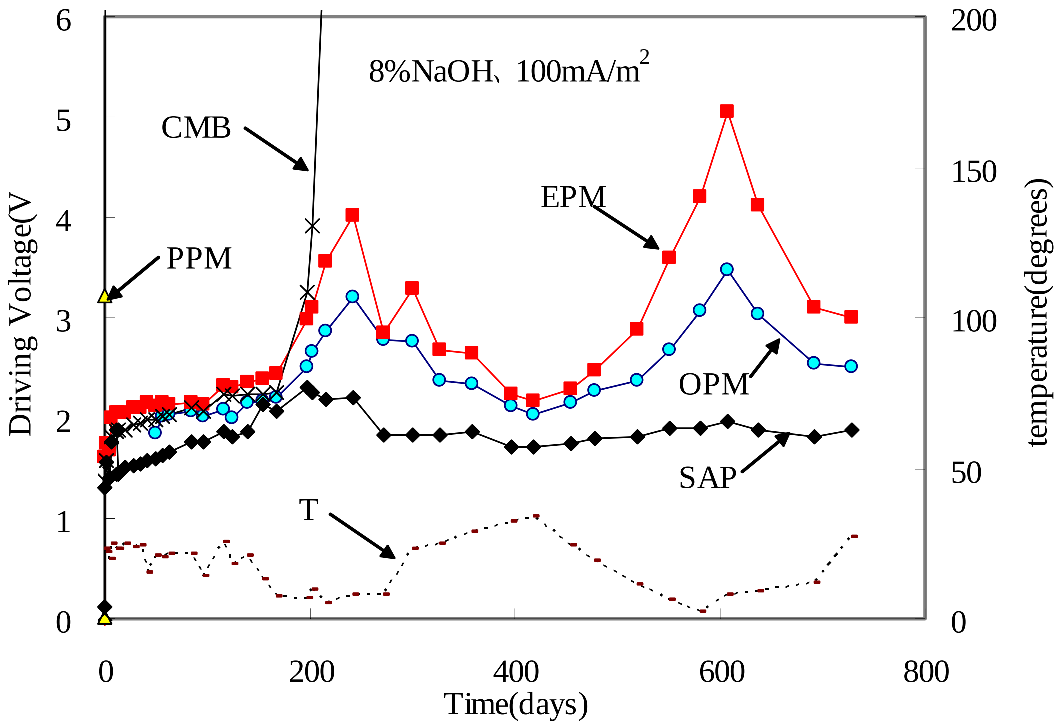

Figure.3: driving voltages

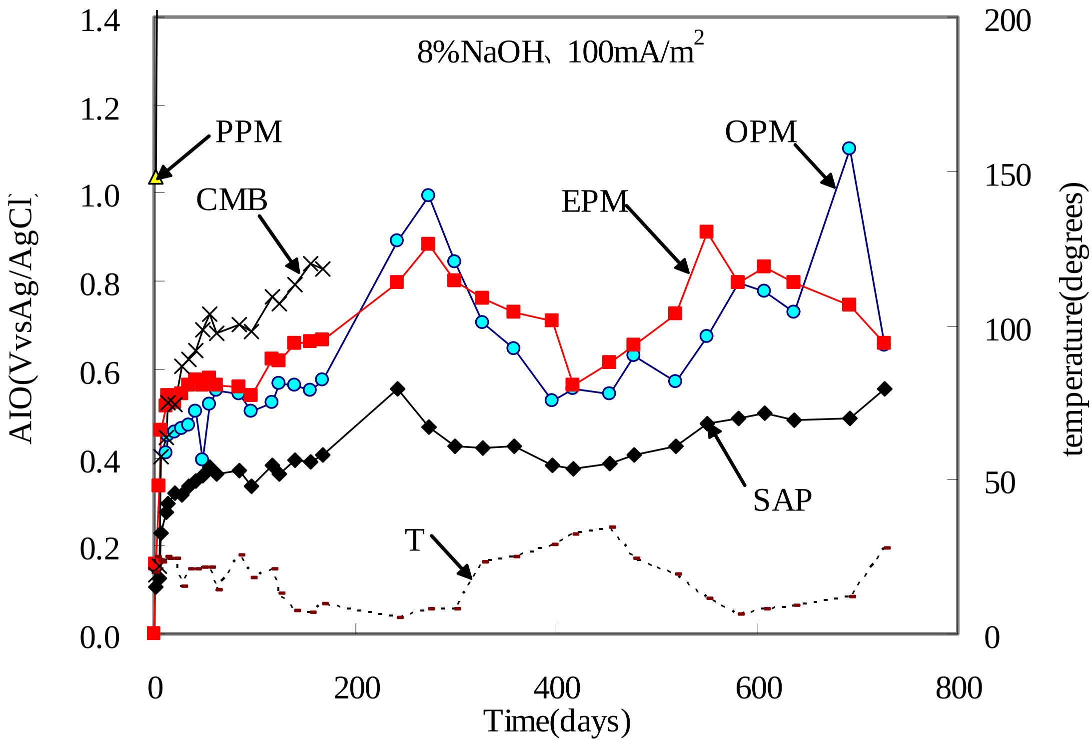

Figure.4: anodic instant off potentials of the anode

4. ANODE NET SYSTEMS

4.1Outline

A anode is required to conduct with ionic between concrete structures and the anode on the concrete surface with surrounded by an solid electrolyte. And If it is placed in mortar as a solid electrolyte surrounded with anode, the anode is required to satisfactory unite with mortar. And so it is provided for uniting mortar of ionic conductor to form net. Third test are started more large blocks of concrete. The basic electrolysis solutions are determined by first test result in range from 4.0 to 8.0 (%)NaOH solutions. and To accelerate positive damage, the impressed current density shall be required to range from 20 to 200 mA/m2.and blocks exposed for outdoor. The parameters are shown in Table.4. Figure.5 shows blocks of concrete. We used Portland cement-300kg/m3,water-cement ratio of 0.5, NaCl -10kg/m3, 600mm long*400mm wide 100mm high, and having a rebar of steel with placed horizontally ,and anode net is placed over the surface surrounded by mortar. The durability of anode in the conditioning is assessed by measuring driving voltage. Ni/CFS anode net shown in Figure.6.

Table.4: The parameter of third test

solid electrolyte	concentration (%)	current density (mA/m^2)
expanded mixture portland cement	0,4,8	20,40,100,200

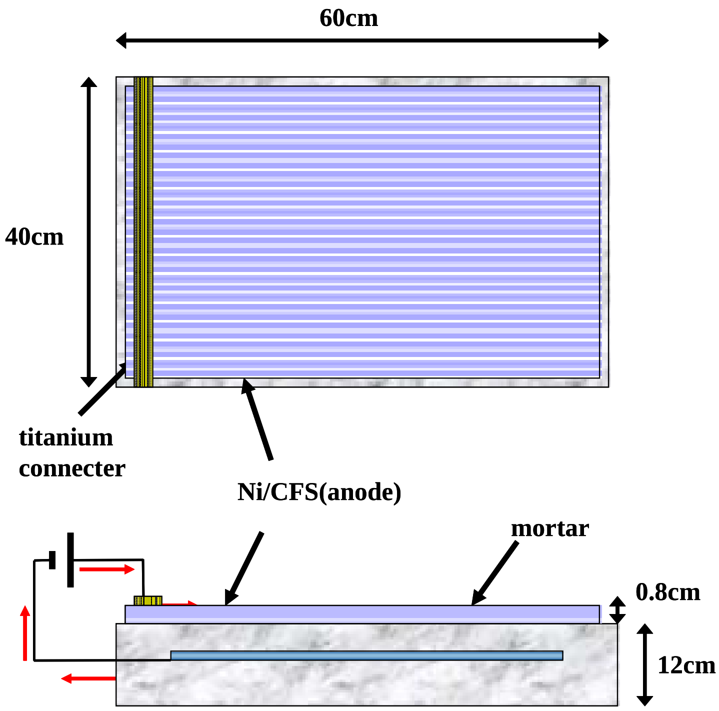

Figure.5: blocks of concrete

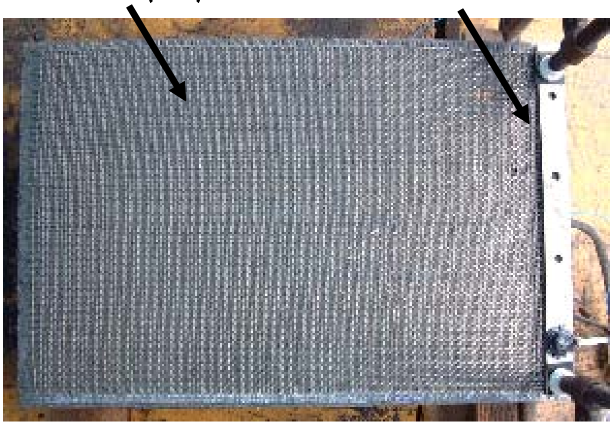

Figure.6:Ni/CFS anode net

4.2 RESALT

Figure.7 and 8 represents driving voltage with concentration of 4, 8 (%)NaOH ,current density with 20~100mA/m2, As can be observed in Figure.7,8, driving voltages are depend on current density. 200mA/m2 of 4%NaOH and 100 , 200mA/m2 of 8%NaOH are immediately begins to increase after 7~14 days. and others anodes continue to perform satisfactorily after more than 1 years.

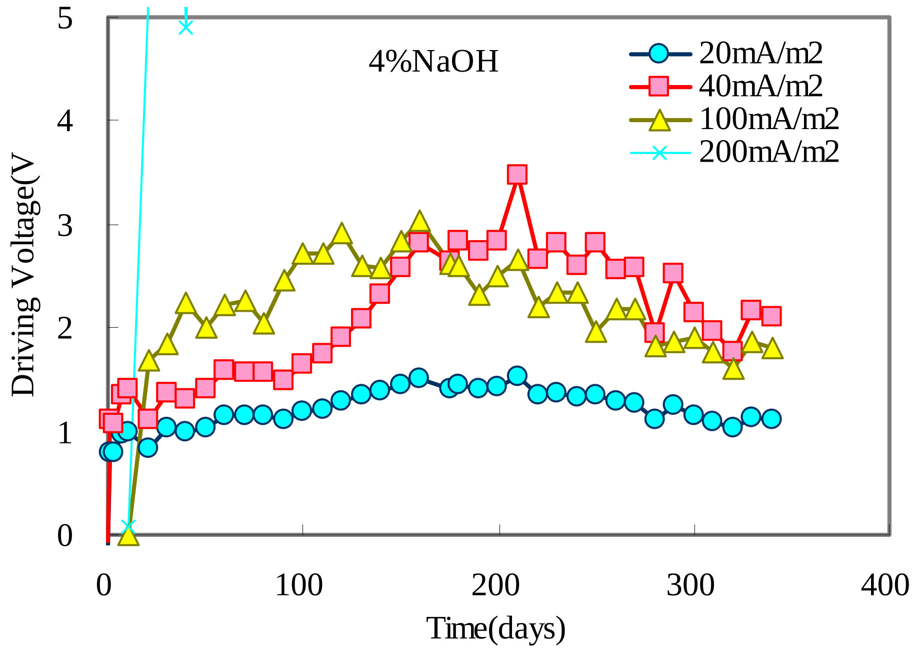

Figure.7: driving voltages

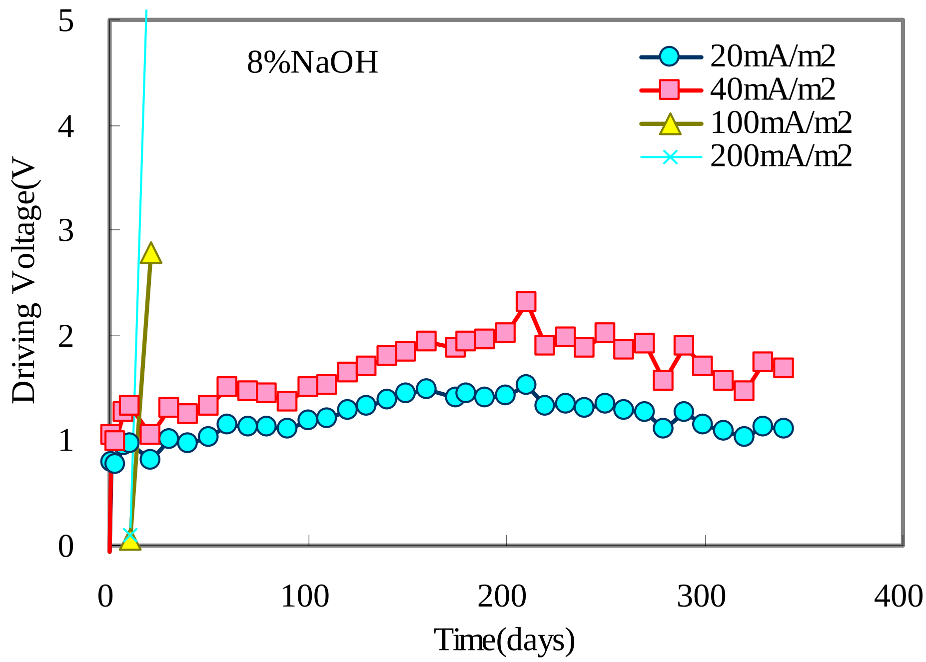

Figure.8: driving voltages

5. ANCHORING ANODE-COMPONENTS

5.1Outline

This chapter describes new cathodic protection method, which consists of Ni/CFS (polyacrylonitrile, cost of about $78/m2 of anode surfaces) anode, super absorbent polymer (polyacrylic acid) ,FRP (fiber reinforced plastics) . Figure.9 shows consists of anode. A system is installed on concrete surfaces by fixing titanium pin which is inserted in a hole prior digged up concrete surfaces. FRP holders of cathodic protection system are placed in backfill to improve in conducting with ionic between Ni/CFS anodes and the surrounding outside. This system is the so-called anchoring anode-components(AAC). Figure.10 shows AAC are fixed on the surface of concrete at regular interval. block of concrete, which is a simulated a bridge. We used Portland cement-277g/m3,water-cement ratio of 0.65, NaCl-12.4kg/m3, 4,400mm long*400mm wide 700mm high, and having a rebar of steel . To accelerate corrosive damage, block of concrete would be exposed in the conditioning for a year, which is a cycle of a one week to spray salt water for a period of three days and dry for a period of t four days. The AAC are impressed in current densities 10mA/m2 of concrete surfaces by measuring E-logI test as polarization function in each of impressed current values. The use of anode in the conditioning is assessed by measuring E-logI test and depolarization values. AAC shown in Figure.10, 11.

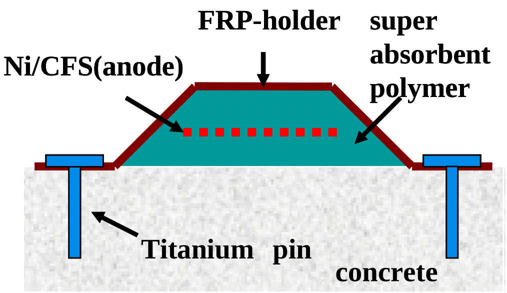

Figure.9: consists of anode

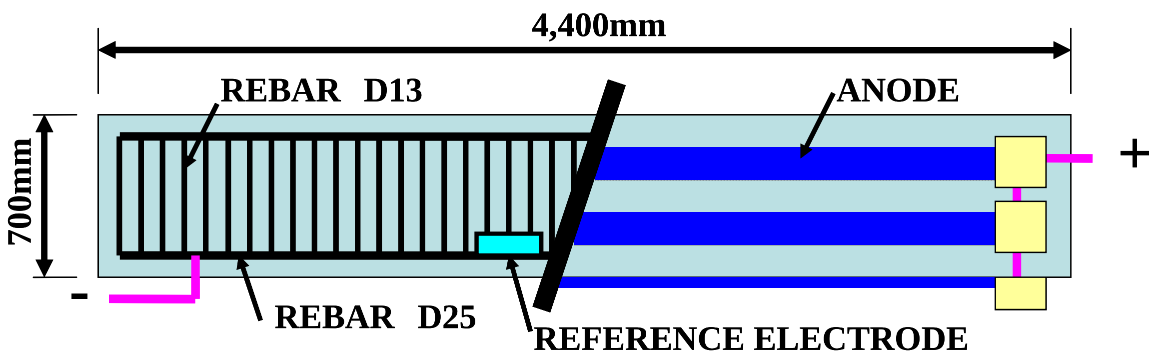

Figure.10:anchoring anode-components

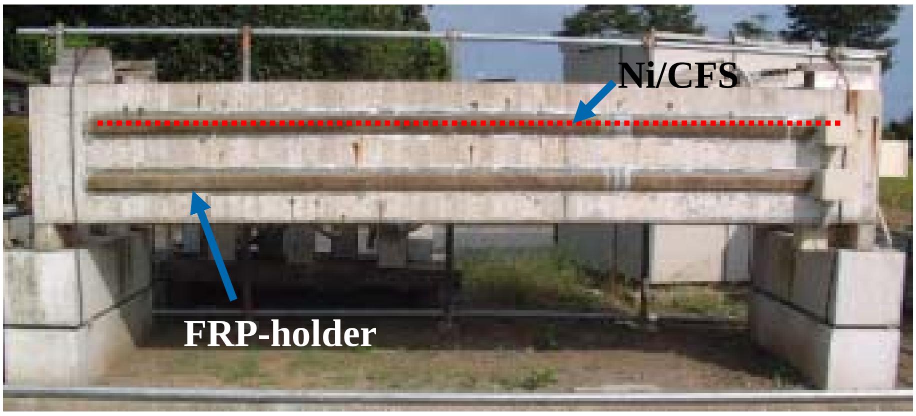

Figure.11: complete view(AAC)

5.2 RESALT

E-logI test data for AAC are shown in Figure.12. 550 days of E-logI curve is larger in the leaning of line than the 1 day, which are indicated to resist against electric chemistry reaction. Four hour depolarization data for AAC are shown in Figure.13. More recent depolarization values are also well above 100 mV. During the 500days of operation depolarization values are large and the rebar is sufficiently protected by the CP system.

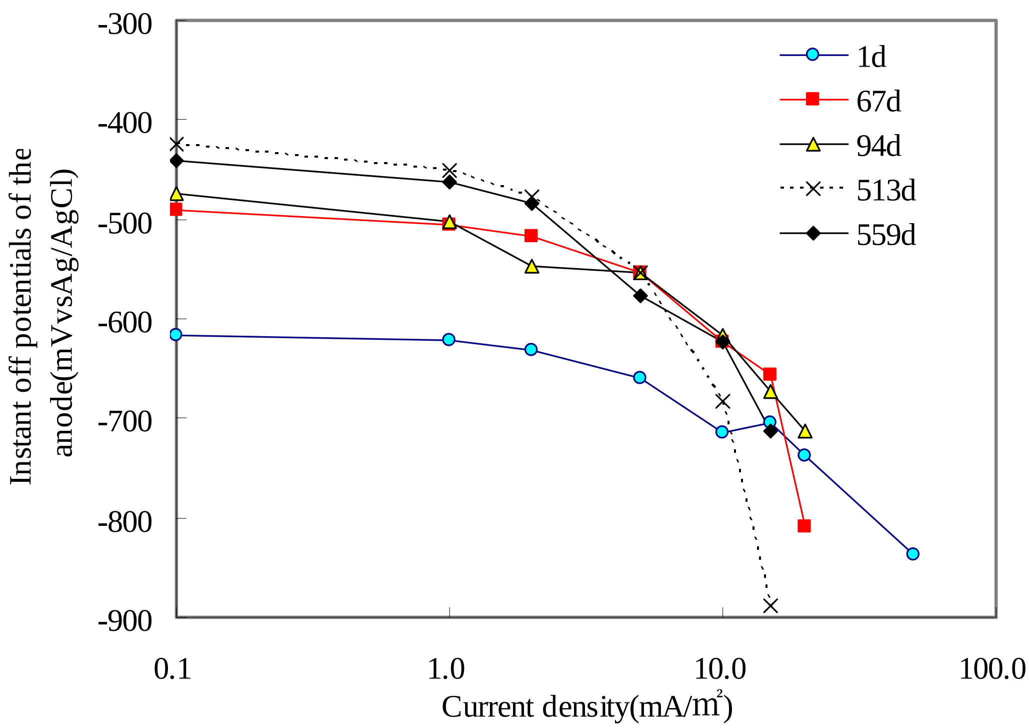

Figure.12: E-logI test

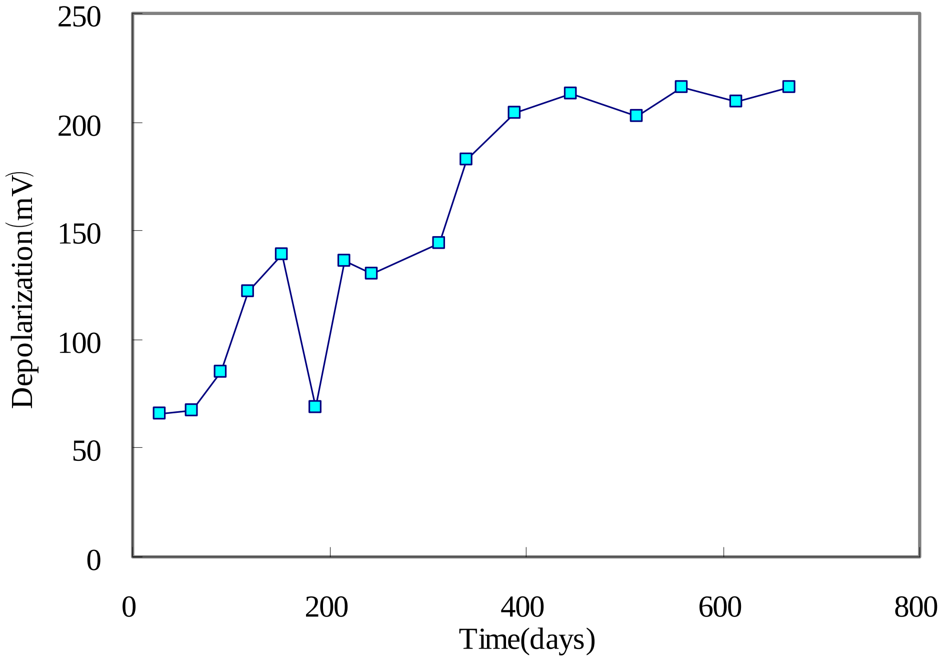

Figure.13: deplarization data

6. CONCLUSONS

1. When the Ni/CFS are immersed in higher than 4%NaOH solutions , they are indicated to be sufficiently corrosion resistance by accelerated life testing, which are impressed current are,20A/m2 , and over period of 180 days, and added 3%NaCl solutions.
2. The solid electrolyte of OPM, EPM, SAP are perform satisfactorily after more than 1 years by testing accelerated positive damage, because of maintaining ionic conductors of solid electrolyte, which are enough to electrify them.
3. The surface-mounted anode-net systems on the block of concrete of used in this experiment are perform satisfactorily after more than 1 years by testing accelerated positive damage.
4. The anchoring anode-components systems on the block of concrete of used in this experiment has successfully provided protection for the rebar over 550 days and is still performance satisfactorily.

7. REFERENCES

NACE (National Association of Corrosion Engineers) Standard TM0294-94 Item No.21225, March 1994.