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Alternating Current(AC) Corrosion Analyzed by Electrochemical Impedance Spectroscopy

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So far, many research results on AC corrosion have been reported but each one is not consistent with another. In order to understand the characteristics and factors affecting on AC corrosion, Electrochemical impedance spectroscopy (E.I.S.) was used and changes in kinetics and surface properties was analyzed. Generally, E.I.S. test has been used mainly for the diagnosis of the concrete corrosion and coating material. However, considering the outstanding functions of E.I.S. test, it can be adopted as a good method to study AC corrosion.

Electrolyte resistance (R_{sol}), double layer capacitance (C_{dl}) and polarization resistance (R_p) are the basic circuit elements. Using the model which is consist of these basic elements, various results of E.I.S. test can be interpreted. And, through this method the mechanism and characteristics of AC corrosion can be explained.

Keywords *: alternating current (AC), electrochemical impedance spectroscopy (E.I.S.), electrolyte resistance, double layer capacitance, polarizatioin resistance.*

1. Introduction

Corrosion damages by alternating current (AC) have been observed in many underground pipelines since 1900's. But most of engineers neglected AC corrosion problem before 1980's because AC corrosion rate is very low and as little as 1% of the rate of same amount DC corrosion.[1)]

In 1986, an investigation regarding to AC corrosion failure of a high-pressure gas pipeline has been reported in Germany. And other cases of AC corrosion failure were reported in Canada and the U.S.[2),3)]

AC corrosion problem can not get avoidable as long as AC power system is used. Furthermore, 3 phases, 4 wires system for the distribution system makes the problem severer as in the case of Korea.[4-13)]

In this paper, several methods have tried to understand AC corrosion mechanism. AC corrosion will be assured and compared to DC corrosion with the weight loss experiments and E.I.S. test. And the mechanism of AC corrosion will be explained.

2. Experimental procedure

The Gas pipeline material (KS D 3607) and SS 40 which are used in the field generally in Korea are selected in the AC experiment. The Fig. 1 shows the shape of the specimens. Each specimen was polished with sand paper (#600) and then rinsed at super sonic cleaning vessel and dried in drying oven. The special power supply instruments were made which can control the current and voltage freely. The schematic of the power supply shows at the Fig. 2. This instrument was used to control AC and DC corrosion directly. To know the characteristic of AC, the various wave form of AC is necessary. Through this apparatus, various form of AC could be made effectively; sinusoidal wave, divided rectifying wave, con

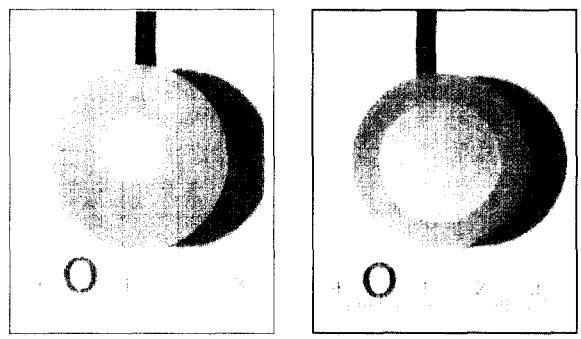

Fig. 1. Specimens

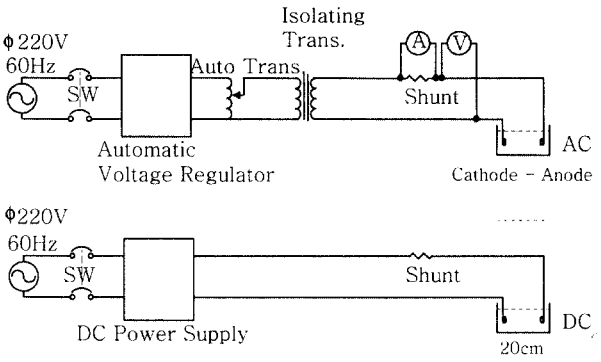

Fig. 2. Schematic of the power supply

Fig. 3. Experimental photograph

secutive rectifying wave, etc.. Fig. 3 is the experimental photograph. Natural sea water and H_2SO_4 solution were used as electrolyte. It can accelerate the corrosion rate of the specimens.

The E.I.S test was used to know the procedure and characteristics of the AC corrosion on the surface of the specimens. CMS 300(Gamry) and SI 1280b(Solatron) were used at these experiments. The AC mechanism will be explained based on those experimental results.

3. Result and discussion

3.1 Characteristics of the DC and AC corrosion

Fig. 4 shows the result of the weight loss test. Through this result we can sure that DC corrosion is definitely severe than the AC corrosion with increasing current aplitute. DGH and DCH are specimens which applied DC to Gas pipeline material and SS 40 in H_2SO_4 electrolyte. DGS and DCS were conducted in sea water. ACH, AGH, AGS and ACS were applied AC. The amount of the AC corrosion is very small compare to DC corrosion. But it made corrosion. So, it can be possible to make corrosion

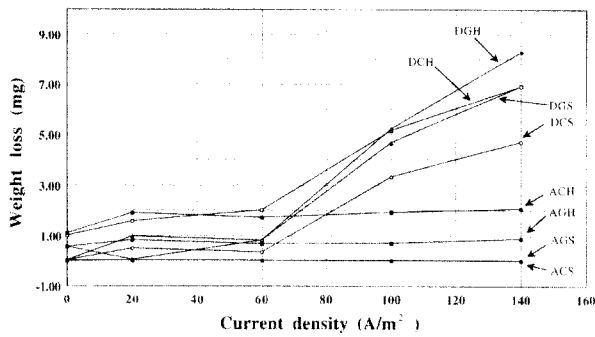

Fig. 4. The result of the weigh loss experiment

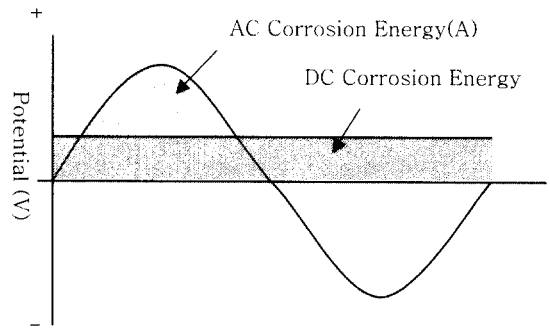

Fig. 5. AC & DC potential used corrosion energy

problems on the metal structures at the near the AC power source. So the special concern of the AC corrosion is necessary.

There is the big difference between AC and DC. AC has a sinusoidal wave, on the contrary DC has horizontal curve. For the occurrence of the electrolytic corrosion, the energy of the corrosion is bigger than corrosion resistance which include the electrolyte resistance and polarization resistance. DC can apply the energy to the specimens continually so, if the DC corrosion starts on the surface of the metal, it just needs a small amount of energy to keep and accelerate corrosion, but AC needs a big energy continually. Simply, AC repeats the change of the phase so when it has positive direction, it helps to occur the polarization but opposite component protects polarization. In Fig. 5, the space A is the possible energy to occur polarization.

3.2 The result of the E.I.S test

E.I.S. test has been recognized as the powerful instrument to know the surface of the specimens. Especially the double layer of the specimens. The mutual reaction of AC help to know the double layer on the surface. Fig. 6 represents anode polarization curve of SS 40 in sea water. The SS 40 specimen shows active polarization characteristic at the whole range of the potential at the

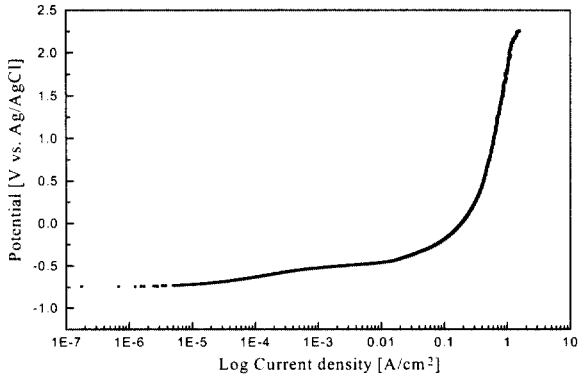

Fig. 6. Polarization curve of the SS 40 in sea water

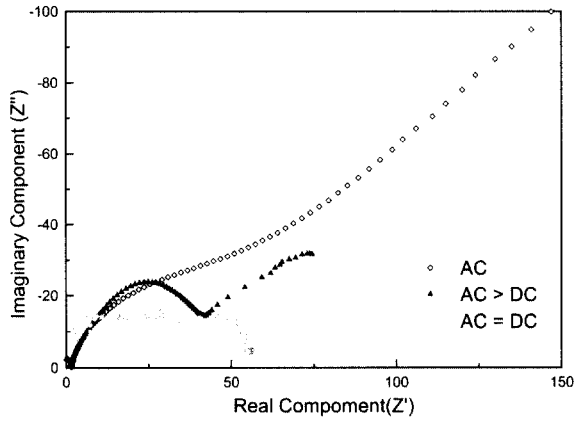

Fig. 7. E.I.S. test result of SS 40 in sea water

graph. So, E.I.S. was conducted when the potential of the specimen is in corrosion potential. Each test was applied different source; A was just applied AC 7.85[mA]. B was applied AC 3.1806[mA], DC 0.3543[mA] and C was applied AC 1.767[mA], DC 1.767[mA]. The capacitance (C_{dl}) is calculated by the frequency, R_{sol}, and R_p.

$$C_{dl} = \frac{1}{2\pi f_{\min} R_p}$$

The capacitance values were decreased with increasing DC amplitude. The one which was just applied AC is 264[uF], the others which applied DC are 621[uF] and 1534[uF] respectively. In fact, the capacitance at corrosion acts as the corrosion barrier on the structure surface. The strength of corrosion barrier increases when DC is applied. As demonstrated in Fig. 5, with increasing DC, the space of the energy is increased. So the increased energy is used to polarization of the metal. And Fig. 7 represents the result of the E.I.S. test.

3.3 Mechanism of the AC corrosion

There are a lot of changes on the surface of the specimens during the corrosion. For occurrence of the corrosion, the double layer must be charged at first, because the double layer is the similar to condenser. Before the condenser is charged the electrons can not flow. So, when AC is applied, positive component current charge in the double layer, and then the excess current affect the corrosion. But AC shows sinusoidal curve. So, it immediately discharge the electrons. When AC flow, the double layer repeat this process.

Generally, DC current can flow continually. There is no discharge process on the double layer easily. Actually the theory of AC corrosion have not explained well yet. But many researchers agree to this kind of process.

The repeated process of the charge and discharge is the most important behavior on the double layer. This is still ongoing study so, the mechanism of the AC corrosion will be studied continually.

4. Summary and conclusions

The amount of the AC corrosion can not be ignored. But it can be possible to make corrosion problems on the metal structures at the near the AC power source. The capacitance values were increased with increasing DC. In fact, the capacitance is the kind of the corrosion barrier. The level of corrosion barrier increases when DC is increased. When AC is applied, at first, positive component current charge in the double layer, and then the excess current affect the corrosion that is to say polarizaiton. But AC shows sinusoidal wave. So, immediately it discharge the electrons. When AC flow, the double layer repeat this process

Now AC corrosion is treated as an unusual corrosion situation. But it may be used as now way to protect DC corrosion.

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