Scratch Area Effect in Coating to Protection Current Needing in ICCP System for AISI 1045 Steel in Sea Water Environment

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Abstract—**Every metal always going back to its oxide form. Steel which are oxidized having lower quality than steel which are not. Oxidizing steel will going faster if it is placed in corrosive environment. Sea water is one of the environment that support the oxidizing process. Coats are using to protect the steel in sea water. But sometimes there is some failure in coating process so the coat will have scratch damage area. The objective of this experiment is to know how much current needed to protect AISI 1045 steel which have been coated with polyethylene and given scratch area with shape variations, in sea water environment. This experiments is the continuation from the past experiences which is using sacrifice anode, on the other hand, this experiences using Impressed Current Cathodic Protection. Data which are taken from this experiment is the differentiation of potential that measured with electrode reference Cu/CuSO4, and the current measured by avometer. With ICCP system, we know that the corrosion rate in rectangular-shape scratch is faster than circle-shape scratch, and the larger the area of scratch, the larger current needed to protect the coated steel.**

Keywords— AISI 1045, sea water, ICCP, scratch shape, current.

I. INTRODUCTION

Nowadays, steel is the primary material which is needed in industrial world. One kind of steel is AISI 1045 steel. This steel often use in many components in advance industrial process, such as piping system or vessel. But, the problem that is often encountered is corrosion. Corrosion is a process degradation of materials because of the environment effect. Corrosion is quiet dangerous because it can decrease the strength of the steel. Corrosion cannot be avoided, but it can be controlled.

The construction which is built in the dock or offshore oil drilling and use steel as the main component, is commonly given some protection to corrosion. Up until now, there are so many method that can be used to maintain corrosion. One of them is coating method. Coating method is done by giving some layers or coat from corrosive environment to contact the steel's surface. Usually, the steel which is protected by this method also equipped with cathodic protection system to optimize the protection. But, in many constructions, especially on the installation, there is always any failure, and it may cause some damage on the coat. Or we called this scratch. This scratch makes some parts of the steel contact with the corrosive environment, in this case is sea water. The part which is not coated can effect the performance of cathodic protection system.

Catodic protection system is one of the corrosion protections by state the whole steel which is wanted to be protected as a cathode. This system is divided into two: cathode protection with sacrifice anode and cathode protection with impressed current or ICCP (Terethewey, 1991). Cathode protection system with sacrifice anode states the metal which is wanted to be protected as the cathode by adding sacrifice metal as anode by calculating its galvanic potential. Cathode should having higher potential than anode. The difference between potential value of cathode and anode will produce some electric current. This current can protect the cathode. On the other hand, ICCP system use the electric current from the power supply, whether AC or DC, which is equipped with rectifier, where the negative pole is connected to the isolated structure and the positife pole will be connected to anode. The electric current will flow from anode through the electrolyte to the structure's surface, and then flowing through the structure and going back to the rectifier by electric conductor, so the structure will be protected..

The advantages of Impressed Current Cathodic Protection are, it can be design to application with high flexibility because it has large capacity range of output current. Which is mean, the current needing can be well controlled manually or automatically by changing it's output voltage as required. Therefore, we will use Impressed Current Cathodic Protection to give more variation of current to AISI 1045 steel which the coatings are already scratched in different area for each steel

Research that have been done by Novian and friends (2012) shows that the larger scratch in polyethylene coat on AISI 1045 steel with aluminum alloy sacrifice anode and immersed in sea water, giving result that the anode corrosion rate increased as the scratch increased. Otherwise, research from Aditya and friends (2012) about the effect of width of scratch in AISI 1045 steel with sacrifice anode magnesium alloy that is immersed in the earth, shows the same result: the larger scratch, the higher corrosion rate, furthermore, the time range that is used to corrosion is faster than the first calculations. So, we continued the research about this scratch area case, and compare the result in ICCP system.

II. METHOD

A. Tools and Materials

The Materials used in this research are AISI 1045 steel, salt, tar and zincromat as coat, Cu-CuSO4

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electrode reference, distilled water, and graphite with specification of dimensions : p = 138 mm and d = 36 mm. The tools used are rectifier, wire, avometer/multimeter, and potentiometer.

B. Procedure Experiment

This experiment is divided into three step: 1) preparation the series of Impressed Current Cathodic Protection, 2) taking the data of current in each system, 3) analyze data of the current needed to protect the steel and connect it with scratch area, including the type of corrosion that occurs on the surface which is uncoated.

The first is preparing the sea water. In this experiments, it is unnecessary to take sea water originally from the sea, but by conditioning distilled water, so it has the same properties as sea water. Sea water contains 3.5% salt, to get distilled water to be like sea water, it can be done by adding salt to the distilled water 3.5% from the weight of the water.

The specimen used is AISI 1045 steel. The dimensions is 100x50x16 mm. and before applied the coat to the surface, steel roughness and rust should be removed first by grinding machine. After that drilling on the edge of specimen, to make a place for wire to be connected to the specimen. After that, making the pattern of scratch like shown in figure 1. After that the steel should be coated with tar, wait until it dried, then coated by zincromat. And for the last, coat is removed as the pattern given.

On sacrifice anode method, specimen which is ready is connected with aluminum alloys as a cathode. Then it is immersed for 20 days and 40 days, and taking the data once every 4 days. Measuring the corrosion rate is using weight loss method, it is done with measuring the difference weight of anode from its initial weight.

For impressed current cathodic protection, finished specimen is connected t rectifier, avometer, graphite, and potentiometer as shown in figure 2. Before running the protection system, the specimen should be immersed to the sea water for 30 – 60 minutes. After that the specimen can be protected by current flow from the rectifier. This step should be finished one by one to prevent mixed data from one specimen to another. The current flow will be measured by avometer. The parameter that used to know whether the steel is protected or not is from the potentiometer. Potentiometer will displaying the different potential between he steel and Cu-CuSO4. It can be said that the steel already protected if the different of potential is 800 -900 mV. The current flow is conditioned until potentiometer showing 850 mV.

C. Container

The container used in this experiment is polymer pipe, the length of pipe is 2300 mm and the diameter is 150 mm.

From the "Standard Guide for Conducting and Evaluating Galvanic Corrosion Test in Electrolytes ASTM G71-81", sea water media is placed in a container with a comparison 40 cm3 for 1 cm2 scratch area of specimen that will be immersed

Volume of electrolyte

$= \frac{1}{4} \pi d^2 t$

$= \frac{1}{4} \pi (15)2 (230)$

= 40644.355 cm3 = 40.65 L ~ 40 L

Scratch area of cathode

40 cm^3 for 1 cm^2, so we can get:

40 cm^3 : 1 cm2

0.04 L : 1 cm^2

For 40.65 L,

$$\frac{40.65}{0.04} = 1016.25 cm^2$$

Total area cathode that can be protected with 40.65L volume of sea water is 1016.25 cm^2

Area of cathode that will be immersed

= (2pl + 2pt + 2lt)

= (2 x 4.5 x 10) + (2 x 1.5 x 10) + (2 x 1.5 x 4.5)

= 133.5 cm2

The maximum hole can be made for pipe:

$$\frac{1016.25}{133.5} = 7.61\ hole$$

In this case, we used 6 kind of scratch (6 specimen) so we need 6 holes in the pipe for all the specimen, and the distance for each hole is x.

$$x = \frac{230}{7} = 32.85\ cm$$

The distance for each hole is 32.85 cm

D. Current needing check

$$RL = \frac{specific\ resitance\ of\ steel}{pipe\ area} = \frac{\rho s}{\pi . t.(OD - t)}$$

RL= pipe arch resistance (Ohms/m)

ρ= specific resistance of steel (ohm-m)

t = width pipe (m)

OD = pipe outer diameter (m)

$$RT = \frac{coat\ resistance}{pipe\ area\ to\ pipe\ length} = \frac{Rc}{A}$$

RT = cross resistance pipe (ohms/m)

Rc = coat resistance

E. Anode needing

$SA_{anoda} = \pi\ x\ d\ x\ l$

l : length of anoda (m)

d : diameter of anoda(m)

Log Y = 3.3 – log ID

Y = years of protection planned (tahun)

ID = anode density current (A/m^2)

Io = SA_{anoda} . ID

Io = anode maximum current flow

SA = anode surface area (m^2)

ID = anode current density (A/m^2)

Qmin = $\frac{It}{Io}$

Qmin= minimum anode needed

It = total current flow used to protect steel

Io = current flow from each anoda (A)

Q = Qmin x (1+SF_2)

Q = used anode

SF_2 = 15 % commonly used.

F. Corrosion measurement

Corrosion measurement is used to know the corrosion rate or corrosion mechanism. The measurement can be done by simple observation or by using electrochemical instrument. Corrosion rate is calculate from specimen's weight loss during corrosion testing by the formula which is taken from ASTM G 1-90 as shown in figure 3.

$$corrosion\ rate = \frac{(K \times W)}{(D \times A \times T)}$$

Corrosion rate	= mils per year (mpy)
K	= constant (3,45 X 10^6)
W	= weight loss (gram)
A	= surface area (cm^2)
T	= immersion time (hours)
D	= density ($gram/cm^3$)

G. Experiment planning

After doing the experiment, we can get data which is planned to be presented in this table 1. This result will be converted to a graphical relation between x = scratch area and y = galvanic current. From the curve, we can analyze how is the relationship between scratch and compare between rectangular shape scratch to circle-shape scratch.

III. RESULT AND DISCUSSION

Galvanic corrosion (also called ' dissimilar metal corrosion' or wrongly 'electrolysis') refers to corrosion damage induced when two dissimilar materials are coupled in a corrosive electrolyte.

When a galvanic couple forms, one of the metals in the couple becomes the anode and corrodes faster than it would all by itself, while the other becomes the cathode and corrodes slower than it would alone. For galvanic corrosion to occur, three conditions must be present:

a. Electrochemically dissimilar metals must be present

b. These metals must be in electrical contact, and

c. The metals must be exposed to an electrolyte

The relative nobility of a material can be predicted by measuring its corrosion potential. The well known galvanic series lists the relative nobility of certain materials in sea water. A small anode/cathode area ratio is highly undesirable. In this case, the galvanic current is concentrated onto a small anodic area. Rapid thickness loss of the dissolving anode tends to occur under these conditions. Galvanic corrosion problems should be solved by designing to avoid these problems in the first place. Galvanic corrosion cells can be set up on the macroscopic level or on the microscopic level. On the microstructural level, different phases or other microstructural features can be subject to galvanic currents.

By using aluminum alloy sacrifice anode, we can get data as shown as table 2 below. And if it is converted in to a graphic, as shown as figure, we can se if corrosion rate in rectangular-shape scratch is higher than circle-shape scratch in same area.

In sacrifice anode, in the same area, 50 mm2, rectangular-shape scratch having its corrosion rate 3.83143 mpy and circle-shape area having its corrosion rate 2.25322 mpy, it is about 4 times lower than rectangular-shape are. In the same area, 100 mm2, the corrosion rate of circle-shape area is 4,93428

And 5,72512 for rectangular area.

The rectangular-shape are have its tendency to make more corrosion, because its sharp edge in rectangular. This sharp edge make possible to sea water for entering some gap or space between the coat and surface. Beside that it will make formation of anode and cathode easier than the no-edge or circle-shape.

The type of corrosion that occur is crevice corrosion. Crevice corrosion is a localized form of corrosion usually associated with a stagnant solution on the micro-environmental level. Such stagnant microenvironments tend to occur in crevices (shielded areas) such as those formed under gaskets, washers, insulation material, fastener heads, surface deposits, disbonded coatings, threads, lap joints and clamps. As oxygen diffusion into the crevice is restricted, a differential aeration cell tends to be set up between crevice (microenvironment) and the external surface (bulk environment). The chronology of the aggravating factors leading to a full. The cathodic oxygen reduction reaction cannot be sustained in the crevice area, giving it an anodic character in the concentration cell. This anodic imbalance can lead to the creation of highly corrosive micro-environmental conditions in the crevice, conducive to further metal dissolution. This results in the formation of an acidic micro-environment, together with a high chloride ion concentration. All forms of concentration cell corrosion can be very aggressive, and all result from environmental differences at the surface of a metal. Even the most benign atmospheric environments can become extremely aggressive as illustrated in this example of aircraft corrosion. The most common form is oxygen differential cell corrosion. This occurs because moisture has a lower oxygen content when it lies in a crevice than when it lies on a surface. The lower oxygen content in the crevice forms an anode at the metal surface. The metal surface in contact with the portion of the moisture film exposed to air forms a cathode.

The same things happen too in Impressed Current Cathodic Protection system. Rectangular scratch having its tendency to need more protection current than circle-shape area. In the same area, 250 mm2, current needing in rectangular-shape area is 2.2 mA, on the other hand, circle-shape scratch need 2.13 mA. The minimum current needing is 2 mA. We can related current needing with corrosion rate. We can said that specimen with higher current needing having higher corrosion rate. If we relate it with the theory,

$$I = \frac{SA.CDt.CB}{1000} X\ (1+SF_1)$$

We can see that SA (area protected is propotional to I (current needing to protection) So, this experiment can be said prove the equation and appropriate with the theory

When a piece of metal is freely corroding, the electrons generated at anodic areas flow through the metal to react at cathodic areas similarly exposed to the environment where they restore the electrical balance of the system. The fact that there is no net accumulation of charges on a corroding surface is quite important for understanding most corrosion processes and ways to mitigate them. However, the absolute equality between the anodic and cathodic currents expressed in the following equation does not mean that the current densities for these currents are equal.

$$I_{anodic} = I_{cathodic}$$

When this equation is expressed in terms of current densities by considering the relative anodic (Sa) and cathodic (Sc) surface areas and their associated current densities ia and ic expressed in units of mA/cm2, for example, it becomes clear that a difference in the surface areas occupied by each reaction will have to be compensated by inequalities in the current densities.

$$I_{anodic} = i_a \times S_a = I_{cathodic} = i_c \times S_c$$

$$i_a = i_c \frac{S_c}{S_a}$$

The implications of the surface area ratio $\mathbf{S_c/S_a}$ in the last equation are particularly important in association with various forms of local cell corrosion such as pitting and stress corrosion cracking for which a large surface area ratio is a serious aggravating factor. It is easy to understand that the effect of a certain amount of anodic current concentrated on a small area of metal surface will be much greater than when the effect of the same amount of current is dissipated over a much larger area. This factor is an important amplifying factor of the anodic current when $\mathbf{S_c/S_c}$ **is** >> **1** and a stifling factor when **it is** << **1** and for sacrifice anode, When metals or alloys are being evaluated, the change in mass is obtained by weighing the specimen before and after exposure and converting that mass change during the exposure period to a penetration rate. Very often, a weld is made along the center of one side so as to be able to assess selected attack of the weld. The standard calculation does not single out such selective attack.

The calculator uses the following equation to estimate the corrosion rate:

$$R = \frac{K(m_b - m_a)}{A(\Delta t)\rho}$$

where:

R = penetration rate (mil/y or mm/y)
mb = mass before exposure (gram)
ma = mass after exposure (gram)
A = total exposed surface area (mm2)
Δt = total exposure time (hours)
ρ = density (g/cm3)
K = constant for unit conversion

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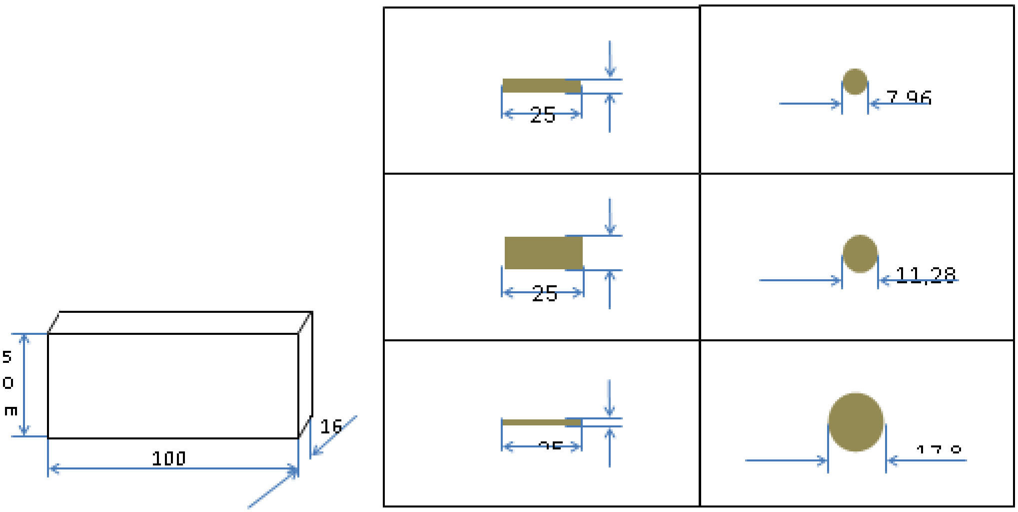


Figure 1. dimensions of specimen and scratch (mm)

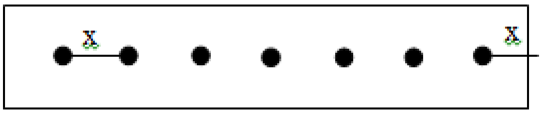
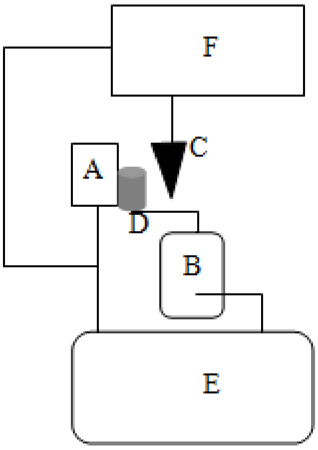
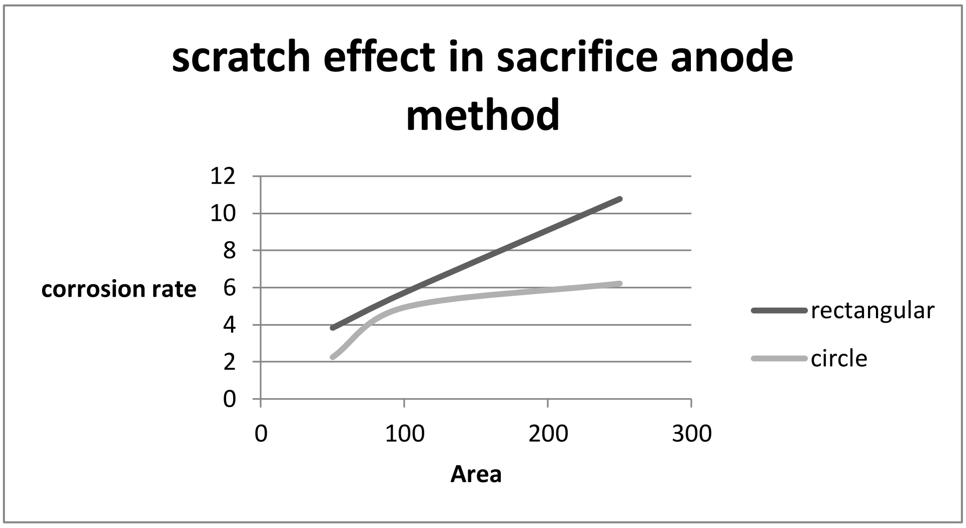


Figure 2. container pipe



A. AISI 1045 steel with variation of scratch
B. Avometer
C. Electrode reference
D. Graphite
E. Rectifier
F. Potentiometer

Figure 3. series system in ICCP



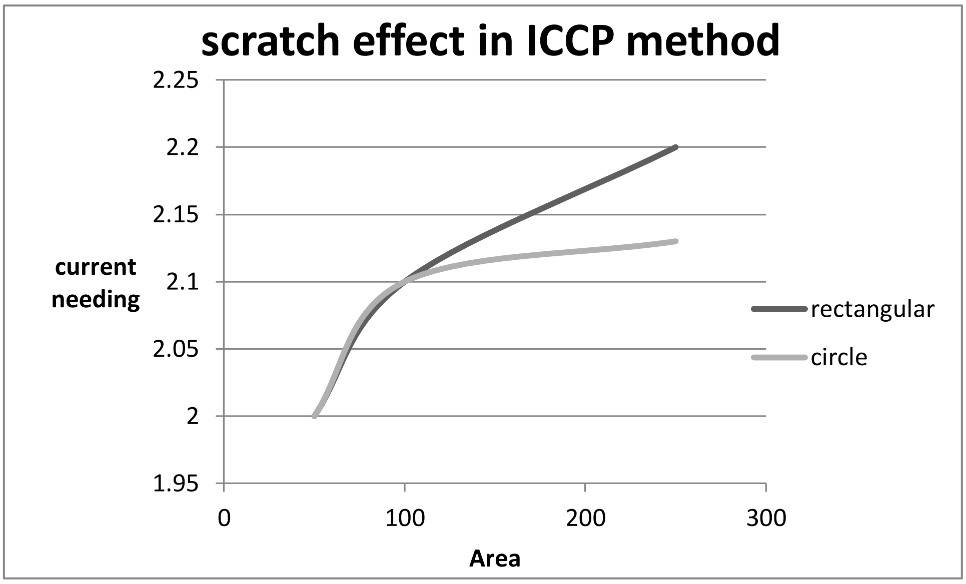


TABLE 1.
TABLE PLANNED TO BE PRESENTED

Specimen scratch area	Potential protection (V)	Galvanic current (mA)

TABLE 2.
COMPARISON BETWEEN SCRATCH AREA, WEIGHT LOSS, AND CORROSION RATE

Shape and size of scratch	**Scratch area (mm^2)**	**Weight loss (gr)**	**Anode corrosion rate(mpy)**
Rectangular, p = 25 mm l = 2 mm	50	0,0403	3,83143
Rectangular, p = 25 mm l = 4 mm	100	0,0497	5,72512
Rectangular, p = 25 mm l = 10 mm	250	0,1343	10,76827
Circle, d = 7,96 mm	50	0,0237	2,25322
Circle , d = 11,28 mm	100	0,0519	4,93428
Circle , d = 17,84 mm	250	0,0654	6,21776
Without coating	0	0,0103	0,97925

TABLE 3.
COMPARISON BETWEEN SCRATCH AREA, GALVANIC CURRENT, AND DIFFERENT OF POTENTIAL

Shape and size of scratch	**Scratch area (mm^2)**	**Galvanic current (mA)**	**Potential different (V)**
Rectangular, p = 25 mm l = 2 mm	50	2	0.851
Rectangular, p = 25 mm l = 4 mm	100	2.1	0.851
Rectangular, p = 25 mm l = 10 mm	250	2.2	0.851
Circle, d = 7,96 mm	50	2	0.851
Circle , d = 11,28 mm	100	2.1	0.851
Circle , d = 17,84 mm	250	2.13	0.851