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Investigation on the Corrosion of Coated Steel Plates with Impact Defect using Divided Steel Plates

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Abstract

A method utilizing divided steel plates was used to investigate the corrosion of coated steel plates with impact defect while continuously submerged in 3% NaCl solution. The polarization behavior of circular divided steel plates was first compared to that of undivided ones. Half-cell potential and polarization resistance results show similar trend in divided and undivided form especially at the later stages of exposure. The method of using circular divided steel plates was then used to monitor the macrocell as well as microcell corrosion in coated steel plates induced with defect. The test results show that the defect causes macrocell corrosion to occur between the defect and sound portions. The impact defect also caused the reduction in the polarization resistance and consequently higher microcell corrosion at the neighbouring sound coated portions.

Keywords: Macrocell Corrosion; Microcell Corrosion; Defect; Coated Steel Plates.

1. Introduction

Under ideal conditions paint coating protects the steel by preventing the access of aggressive elements. It is one of the practical materials used to protect metals against corrosion [1, 2]. However, a coated steel structure exposed directly to the harsh water of the sea can be hit or bombarded by floating objects that leaves impact defects on the coating surface. It is on these impact defects where the steel substrate becomes directly exposed to the aggressive elements of the marine water thus allowing the process of corrosion to instigate. With time, the impact defect can even influence the corrosion of the sound coated portions at the vicinity of the defect. It is reported that once the corrosion is instigated on steel panel protected by an organic paint system, growing blisters appear on the intact portions followed by rapid deterioration [3, 4].

In order to monitor corrosion at the defect and sound portions, the impedance measurement technique was used. In the work of Schmidt, Shaw, Sikora, Shaw, and Laliberte [3], the impedance at the lowest frequency was used to evaluate the corrosion protection performance at the defect and intact sites. The areas for examining the defect and sound portions were controlled using specialized conducting agar cells. However, this technique can only be used when measurement is done in atmospheric exposure conditions.

In this study, the examination of corrosion at the defect and sound portions while in submerged exposure condition was made possible by using divided steel plates. An important feature of the divided steel plate is that its steel

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elements can be connected and disconnected to one another. Therefore divided steel plates basically allow one to control which steel element (defected or sound) will serve as the working electrode for examination even while the assembly is continuously submerged in the bulk solution.

Also part of this study is the measurement of microcell as well as macrocell corrosion currents. Microcell corrosion was calculated from the difference of the low and high frequency impedance while macrocell corrosion current that flows between the defect and sound portions were measured using a zero resistance ammeter. Both corrosion currents were used to evaluate the corrosion behavior in coated steel plates with impact defect. The concept of microcell and macrocell corrosion is shown in Figure 1.

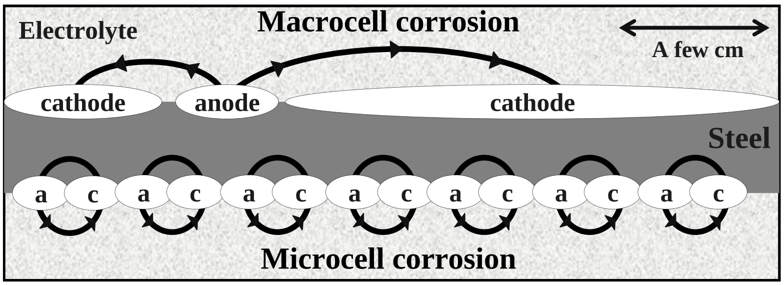

Figure 1. Concept of Macrocell and Microcell corrosion [5]

With these two concepts, the corrosion behavior in coated steel plates with defects is better presented in detail. Microcell corrosion is the type of corrosion in which the anode and the cathode are adjacent to each other in a microscopic scale. This type of corrosion occurs uniformly throughout the steel surface. On the other hand, macrocell corrosion is the type of corrosion in which the anode and the cathode are physically separated by some finite distance away from each other on the steel surface. Macrocell corrosion on the steel surface occurs when the individual parts of the steel surface are exposed to different environment situations. Different environment situations generate potential difference on the steel surface. The macrocell corrosion current can then flow from the parts with high potential to the portions with low potential on the steel surface [6]. The presence of defects in coated steel plates creates a similar situation since the defect part is directly exposed to the high chloride ion content of the marine environment, thus creating a potential difference with the sound or intact coated parts of the surface.

The method of divided steel plates allows for convenient measurement of macrocell and microcell corrosion. This is because of its unique configuration of having its steel elements being connected or disconnected to one another. However, in order to investigate the macrocell corrosion occurring between the defect and the sound portions, it is necessary to develop a method that can measure the macrocell current flowing between the said parts and at the same time clarify the location of the anodic and cathodic parts at each stage of corrosion. Likewise, it is necessary to determine the polarization behavior of sound coated portions located at the vicinity of the defect.

In 2007, Otsuki, Min, Madlangbayan and Nishida published a method that can address the measurement of macrocell as well as microcell corrosion in coated steel plates with unpainted defects [7]. The method utilized divided steel plates as shown in Figure 2. An important feature of the divided steel plate is that its steel elements can be connected and disconnected to one another. When the lead wires are interconnected, the divided steel plate has its elements connected and can therefore act as an undivided steel plate. When the lead wires are disconnected from each other, zero resistance ammeters can be connected to the lead wires between each element. This way, the steel elements are reconnected to one another thus the assembly can once again act as an undivided steel plate. Zero resistance ammeters can be conveniently used to measure the macrocell current flowing between its steel elements. Also, the polarization resistance at each steel element can be measured on a periodic basis. The polarization resistance values can in turn be used to express the microcell corrosion current density at each element. Therefore with the use of the divided steel plate evaluation method, a way to present the details of the macrocell as well as microcell corrosion of coated steel plates was made possible.

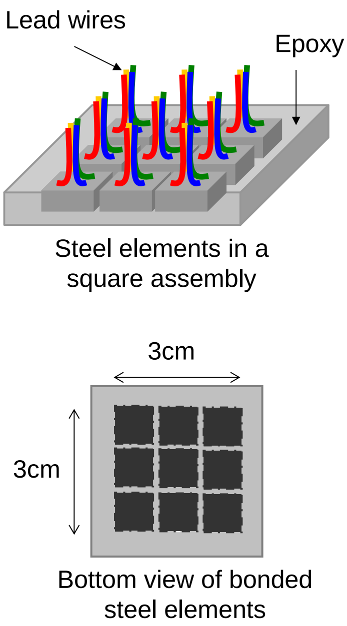

Figure 2. Square divided steel plates developed by Otsuki, Min, Madlangbayan and Nishida [7]

The objectives of this study are stated as follows:

(1) to determine the validity of using circular divided steel plates for measurement of corrosion current densities at the defect and sound portions and

(2) To investigate the macrocell and microcell corrosion behavior of coated steel plates with impact defects.

2. Materials and Methods

2.1. Specimen Preparation

In this study, the method of using divided steel plates was further refined. Divided steel plates in circular form were developed and fabricated. It was fabricated by using an assembly of 5 concentric steel rings around a circular plate as the common center (Figure 3). The rings and center plate follow the Steel Structure 400 (SS400) conforming to the Japanese Industrial Standard (JIS G 3101) specification. Each steel element was chemically cleaned by sequentially soaking it in 10% diammonium hydrogen citrate bath for 24 hours, rinsing in pure water and finally drying in an air tight container filled with moisture absorbing silica gels. After drying, each steel element was soldered with lead wires and then bonded with the other steel elements using slow curing epoxy having a spacing of 0.17cm forming a 12.5cm circular divided steel plate as shown in Figure 4. The lead wires were then interconnected to each other, and by doing so, all the divided steel elements became interconnected to one another thus acting as a unit steel plate. For comparison purposes, undivided circular steel plates, following the same grade and specification, were prepared as well.

Steel cut into concentric rings

Figure 3. Divided steel plates in circular form

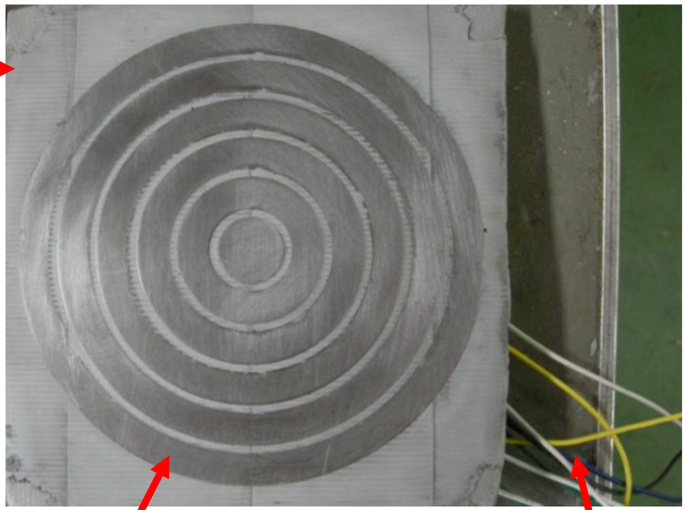

Figure 4. Circular divided steel plates bonded in epoxy

In the investigation of corrosion in coated steel with impact defect, 12.5 cm diameter divided circular plates described and prepared in the first set of experiment were coated with oil alkyd paint, the details of which are shown in Table 1. The thickness of the coating, measured using a commercial thickness gauge, was 80-150 µm. After the application of the coatings was completed, the center plates of the divided steel plates were induced with 4KGm impact following the method in ASTM International (G14-88).

Table 1. Coating properties

Property	Oil Alkyd (OA)
Thickness (μm)	80-150
Substrate Preparation	Sandblasting
Primer Coating	None

2.2. Test Procedure

In the experiment for the evaluation of the method of using circular divided steel plates, bare divided and undivided steel plates were submerged in 3%NaCl solution as artificial sea water. The halfcell potential and polarization resistance in both divided and undivided forms were then monitored every week for an exposure time of up to 1 month.

In the experiment for corrosion behavior, the divided steel plates coated with oil alkyd and induced with impact defect were submerged in 3%NaCl solution. The macrocell corrosion and microcell corrosion of the coated divided steel plates were then investigated every month for an exposure time of up to 4 months.

The macrocell corrosion current flowing between the steel elements of the divided steel plates was measured using zero resistance ammeters (ZRA). The measurement set-up is illlustrated schematically in Figure 5. The lead wires of each steel element were first temporarily disconnected from each other. Zero resistance ammeters were then connected to the lead wires thus effectively reuniting all the steel elements together as single circular plate. The actual test procedure is shown in Figure 6.

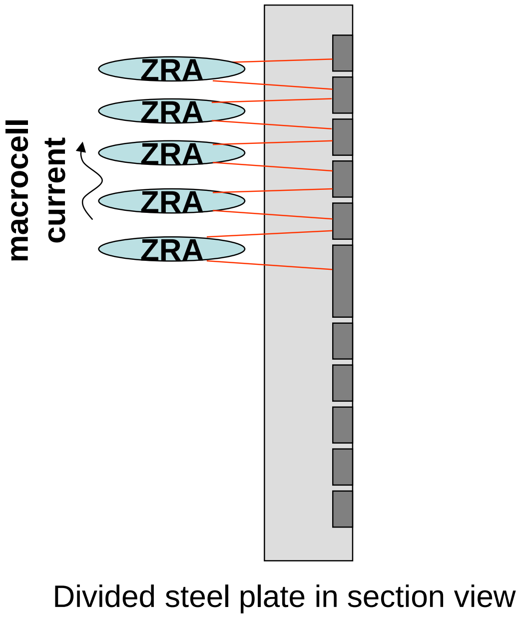

Figure 5. Illustration of measurement of macrocell corrosion current

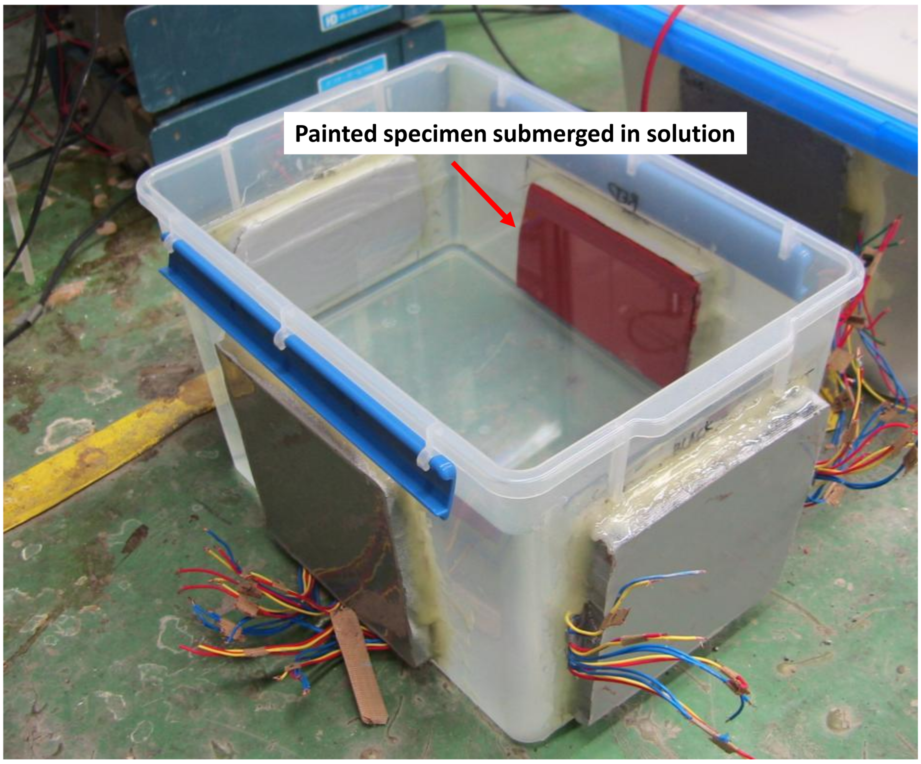

Figure 6. Submersion of painted steel plates in artificial sea water

The macrocell current density for each steel element was calculated by using Equation 1.

$$I_{macro} = \frac{I_{i-1,i} - I_{i,i+1}}{S_i} \times 100 \quad (1)$$

where I_{macro} is the macrocell corrosion current density (A/cm^2); S_i is the surface area of steel element (cm^2); $I_{i-1,i}$ is the current flowing from steel element i-1 to steel element i (A); and $I_{i,i+1}$ is the current flowing from steel element i to steel element i+1 (A).

For sign convention purposes, the anodic current was denoted as positive, while the cathodic current was denoted as negative. Chloride-contaminated water was prepared by mixing sea salt and purified water at 3% concentration by weight of solution.

The halfcell potential and polarization resistance of all steel elements were monitored periodically using the three electrode cell setup of the AC impedance corrosion monitor (Riken Denshi Corrosion Monitor-CT7). The reference electrode used was Ag/AgCl while a stainless steel plate was used as the counter electrode. The measurement setup is shown in Figure 7. The lead wires of each steel element were temporarily disconnected from each other. For every measurement, one wire is connected to the corrosion monitor to act as the working electrode. Therefore divided steel plates basically allow one to control which steel element will serve as the working electrode for examination while the assembly is being submerged in the bulk solution. After each steel element has been used as the working electrode in each measurement, the lead wires were once again interconnected.

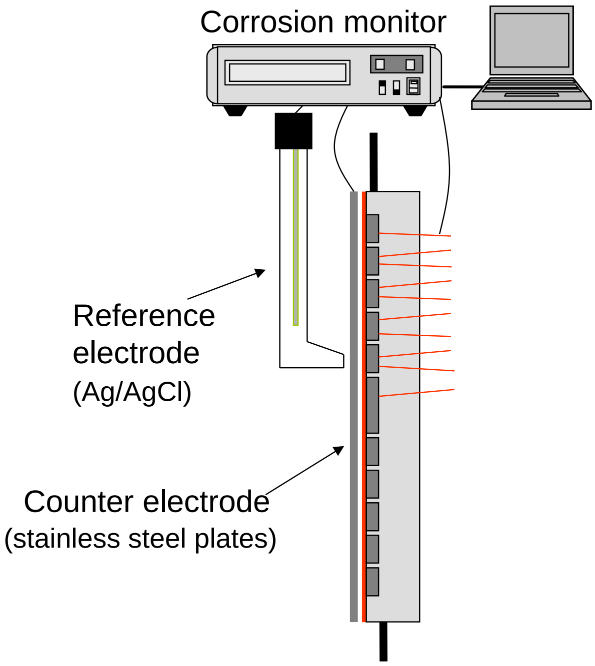

Figure 7. Measurement of halfcell potential and microcell corrosion current

The corrosion monitor used in this study can be set to operate and measure the impedance at a low and a high frequency. The polarization resistance was taken as the difference of the impedance values between the low frequency of 10mHz and high frequency of 10KHz. It was then used to calculate the microcell corrosion current density using Equation 2.

$$I_{micro} = \frac{K}{R_p S} \quad (2)$$

Where I_{micro} = microcell current density (A/cm^2), K is the constant (=0.0209V for steel), R_p = polarization resistance (Ω) and S = surface area of the steel element (cm^2).

3. Results and Discussion

3.1. Similarity between Divided and Undivided Circular Steel Plates

The results of the monitoring of the halfcell potential and polarization resistance of the bare or uncoated divided and undivided steel plates for a period of 4 weeks are shown in Figure 8. The results confirm that the trend of halfcell potential and polarization resistance of the divided steel plate is very similar to that of the undivided form especially at the later stages of exposure. This indicates that a divided steel plate has the capacity to act as an undivided steel plate by showing similar polarization behavior. This finding is important because it becomes possible to measure the macrocell corrosion current between two separate areas of a steel plate using zero resistance ammeter as the measuring instrument. Thus in this study, measurement of macrocell corrosion for coated steel plates proceeded.

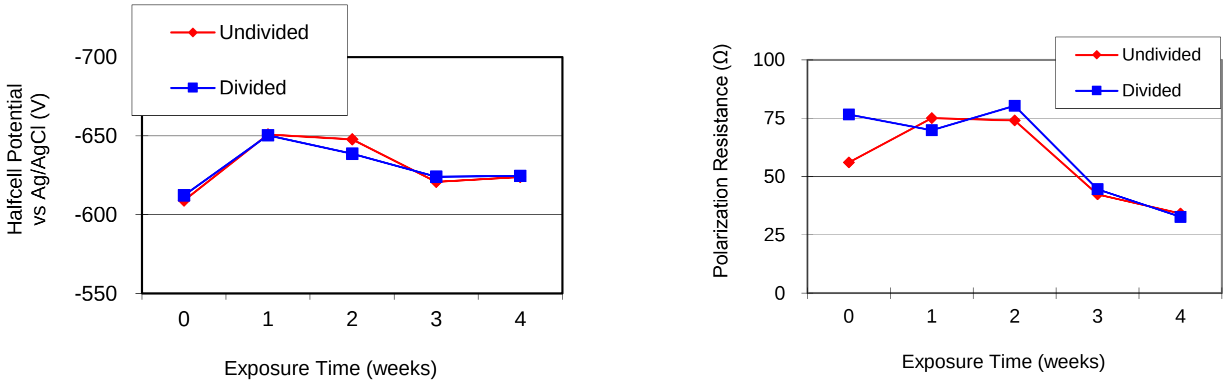

Figure 8. Halfcell potential and polarization resistance of divided and undivided steel plates

3.2. Influence of Impact Defect on Corrosion

The influence of impact defect on steel plates coated with oil alkyd paint was assessed by measuring the macrocell and microcell corrosion current density at the defect part and at the sound parts through the use of divided steel plates. The results of the investigation of macrocell corrosion current density are presented in Figure 9. It was confirmed that macrocell corrosion occurred between the steel element with impact defect and the steel elements with sound coating. The center steel element with impact defect acted as the anode while the rest of the surrounding sound steel ring elements all acted as cathode. However, this was not the case for all steel elements throughout the duration of the four month exposure period. The steel element labeled as “ring 5” acted as cathode from 0 to 2 months exposure period. But during the third and fourth month exposure period, it acted as anode. This shift in polarity can be explained by the fact that during the first two months of exposure, as ring 5 underwent cathodic reaction, its coating may have experienced early loss of bonding from the steel substrate [8]. By the third month exposure period, the coating may have degraded and ruptured leaving ring 5 with no protection at all. At this point, the center steel element and ring 5 become the anodic elements in the macrocell corrosion process.

In the case of the divided steel plates without impact defect, it was observed that there was no macrocell corrosion that occurred even until the 4th month exposure time. Therefore it can be deduced that impact defect can be a cause of macrocell corrosion and therefore its occurrence should be prevented as much as possible.

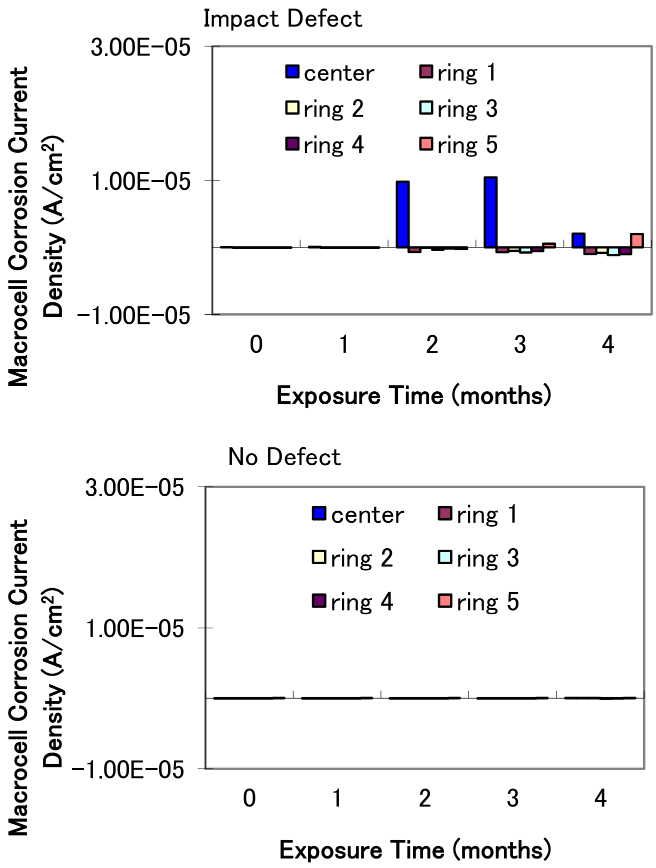

Figure 9. Macrocell corrosion current densities

The results of the microcell current density tests in oil alkyd coated steel plates are shown in Figure 10. It was confirmed that the microcell current density at the steel element with impact defect is much higher than the surrounding steel elements with sound coating. It was observed that the microcell current density of the steel elements with sound coating increased with time. This indicates that polarization resistance of the steel plate decreased as the corrosion activity underneath the coating increased.

In the case of the coated steel plate specimens without impact defect, the microcell current density values at the sound coated steel rings were lower throughout the 4 month exposure time compared to the specimens induced with impact defect. This confirms that in coated steel plates, the impact defect can influence the corrosion resistance of its neighboring sound portions by causing a reduction in their polarization resistance thus causing the increase in their microcell current densities.

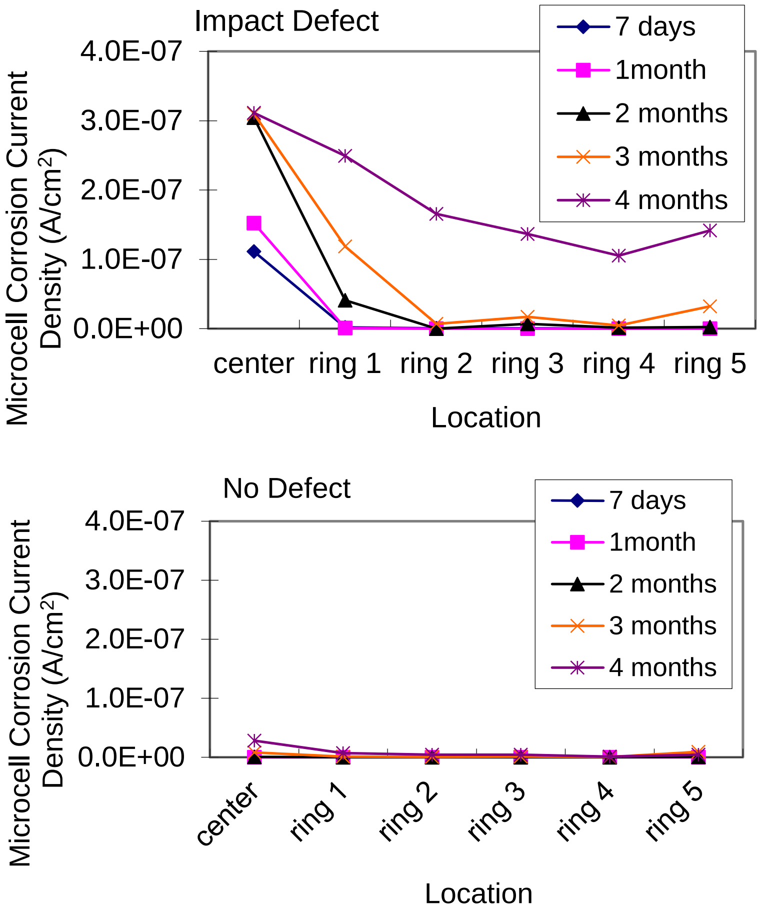

Figure 10. Microcell corrosion current densities

3.3. Relationship between Macrocell and Microcell Corrosion

In this study, the relationship between macrocell and microcell corrosion can also be seen. In Figure 10, the microcell corrosion at the outer rings gradually increased with time. For the same period of time, the macrocell corrosion for the said rings also gradually increased (Figure 9). The reason for this is that the coating on the outer rings degraded due to cathodic reaction during macrocell corrosion process. During this process, the defect area at the center ring acted as the anode while the outer rings acted as cathode. Consequently, this process led to the degradation of the coating in the outer rings that eventually paved way for the gradual increase in the microcell corrosion. The same finding was discussed in the study of Nishida, Otsuki, Annaka and Wada. [9].

4. Conclusions

The conclusions derived from the results of the laboratory investigation are summarized as follows:

(1) The circular divided steel plate has the capacity to act as an undivided steel plate by showing similar trends in halfcell potential and polarization resistance behavior therefore its use as a method to investigate the macrocell corrosion and microcell corrosion in steel plates is valid;

(2) The use divided steel plates allowed for the measurement of corrosion at the defect and sound portions of the coated steel plates under continuous submersion to 3% NaCl solution. The impact defect caused macrocell corrosion to occur between the defect and sound portions. It also contributed to the reduction in the polarization resistance and consequently higher microcell corrosion current densities at the sound coated portions.

5. Acknowledgments

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