

# Area Ratio of Cathode/Anode Effect on the Galvanic Corrosion of High Potential Difference Coupling in Seawater

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**Abstract.** The galvanic corrosion behaviours of copper nickel alloy(B10)/low-alloy high strength steel(921A) and commercially pure titanium(TA2)/low-alloy high strength steel (921A) was studied by electrochemical method in seawater with different cathode/anode area ratio(Sc/Sa). Results indicated that 921A is the anode and B10 and TA2 is the cathodes. The Sc/Sa has a significant impact on the galvanic corrosion, galvanic corrosion rate of high potential difference coupling showed linear growth with the Sc/Sa, but had extreme because the galvanic potential shift and driving voltage decreases.

## 1. Introduction

Considered structural factors, the use of a variety of metal materials with electric connection characteristics is inevitably in ocean engineering. Galvanic corrosion resulted by the harsh environment of seawater corrosion is very harmful, which always lead to corrosion failure problems. [1-3]. To protect the reliability and performance design of marine equipment, the integrated study of galvanic corrosion behaviours is very necessary. Cathode/anode area ratio and the cathode and anode corrosion resistance were two major factors [4-6].

The aim of this study was to study the effect of cathode/anode area ratio on the galvanic corrosion of copper nickel alloy(B10)/low-alloy high strength steel (921A) and commercially pure titanium(TA2)/low-alloy high strength steel (921A) in seawater by electrochemical method.

## 2. Experimental details

In this study, commercially pure titanium (0.024% N, 0.111% Fe, 0.024% C, 0.16% O, 0.001% H, Bal. Ti), copper nickel alloy (0.834Mn, 10.13Ni, 0.0059C, 0.005S, 1.71Fe, 0.026Zn, 0.01Pb, Bal. Cu) and the low-alloy high strength steel 921A (2.27% Ni, 0.12% C, 0.33% Si, 0.37% Mn, 0.08% Pb, 0.04% S, 0.08% V, 0.24% Mo, 1.05% Cr, Bal. Fe) were used. The size of the test sample was 60 × 20 × 3mm, the material sample surfaces were polished to 600 SiC grit by equipment. Then wash offending material sample with acetone, followed by alcohol rinse and post bakes. And the testing sizes of test sample covered partially by use of Model number AB resin adhesive so as to ensure the effective action areas of test sample to 20:1, 40:1, 100:1, 200:1, 400:1, 500:1, 600:1. The test samples were stored in drying vessel before use. In the study, test water was natural seawater taken from the North Yellow Sea.

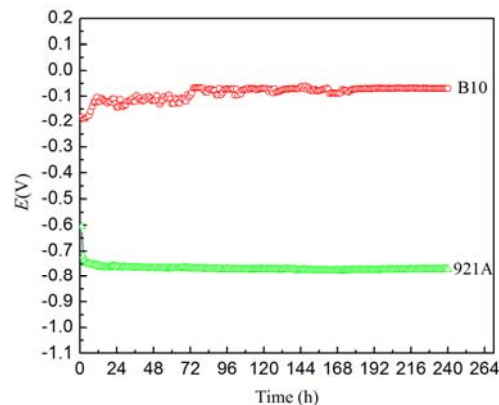
This paper adopted electrochemical method, such as the multichannel zero resistance ammeter, polarization curve method to study the corrosion behavior of bimetal coupling system of TA2/921A, B10/921A in seawater. The measurement of galvanic corrosion potential was studied by using silver



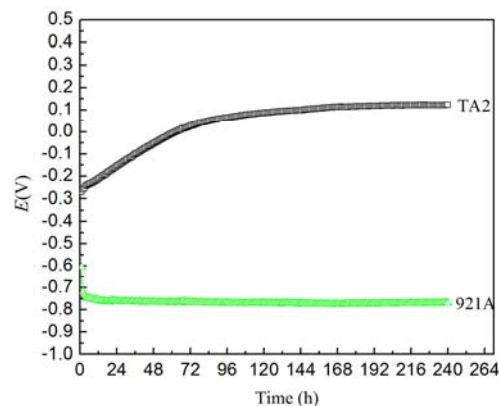
electrode as indicator electrode. At the same time using saturated calomel electrode as reference electrode. The galvanic potential and current was re-estimated during 240 hours after test beginning, at 1 h intervals. And the effects of area ratio of cathode to anode on galvanic corrosion behavior were investigated.

### 3. Results and discussions

#### 3.1. the Self-Corrosion Behavior of the Alloys



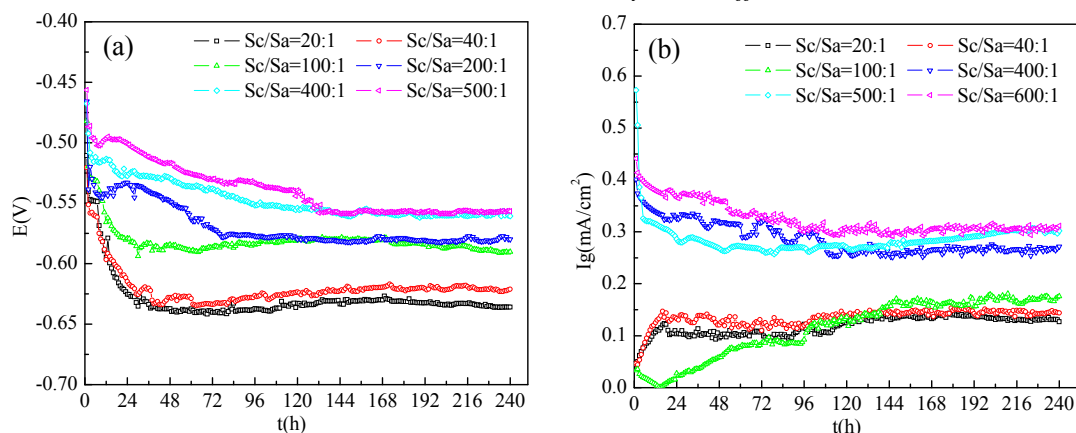
**Figure 1.** Free corrosion potential of 921A and B10 in natural seawater for 240h



**Figure 2.** Free corrosion potential of 921A and TA2 in natural seawater for 240h

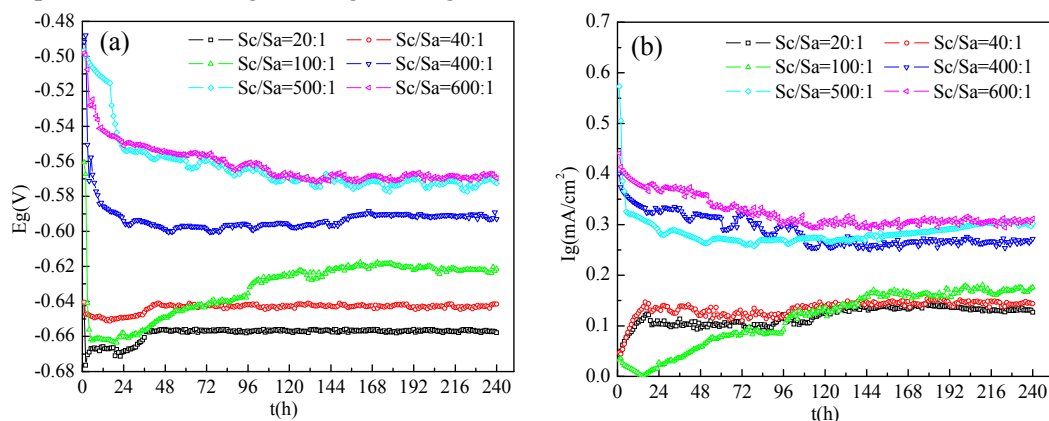
The self-corrosion potential data points of 921A and B10, 921A and TA2 in seawater at 25°C were showed in Fig.1 and Fig.2 respectively. The Fig.1 showed that the self-corrosion potential of B10 is -71.8mV and 921A potential is -781 mV. Result of Fig.2 that self-corrosion potential data plots of TA2 and 921A is 132mV and -781 mV respectively. They all belong to high potential difference coupling. A conclusion can be drawn from above experimental results that the highest electrochemical activity is the of high strength steel(921A) among three alloys. So the galvanic corrosion will occur because of the potential difference between them. So that means that B10 would be the cathode and the 921A would be the anode in the galvanic couple B10/921A, and TA2 would be the cathode and 921A would be the anode in couple TA2/921A.

### 3.2. Galvanic Potential and Galvanic Current Density with Different Sc/Sa



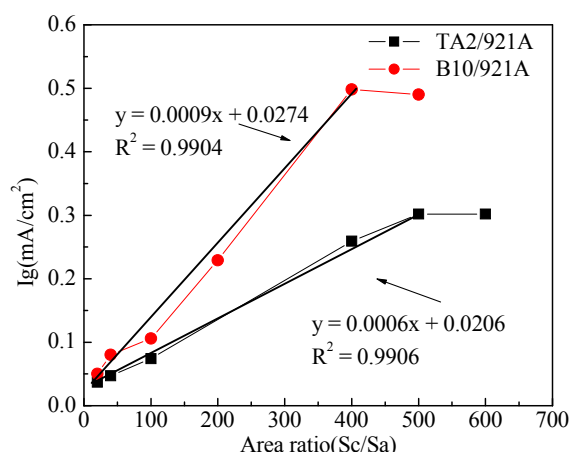
**Figure 3.** The curve of galvanic potential and current density of B10/ 921A with different Sc/Sa:  
(a) galvanic potential, (b) galvanic current density

In Fig.3(a) it is clearly seen that, the mean values of galvanic current densities generally attain their steady states after about 3d immersion for all coupled pairs with different Sc/Sa. The galvanic potential move along with the increase of area ratio, but still be near to the self-corrosion potential of 921A. It can be found obviously in Fig.3(b) that changes of Sc/Sa can cause an increase of the galvanic current density. When the area ratio is more than 400, galvanic potential stability around to -556mV, galvanic current stable at around to  $497\mu A \cdot cm^{-2}$ . The results show that galvanic current and galvanic potential is no longer changes along with the increase of Sc/Sa, then it reaches limit.



**Figure 4.** The curve of galvanic potential and current density of TA2/ 921A with different Sc/Sa:  
(a) galvanic potential, (b) galvanic current density

The galvanic potential galvanic current of TA2/921A galvanic couple with different Area ratio (Sc/Sa), changing with time curve as shown in Fig.4. The galvanic potential of TA2/921A shifted to positive with increasing of area ratio(Fig.4a). The galvanic current along with the increase of Sc/Sa increased significantly in Fig.4b. This is very similar to the experiment results of B10/921A. It can be explained that the anode current is always equal to the cathode current when the galvanic corrosion occurs, and anode area is smaller, the anode current density is greater. That is, the corrosion rate of anode metal is greater. When the area ratio is more than 500:1, galvanic potential and current density of B10/921A stability around to -570mV and  $300\mu A \cdot cm^{-2}$  respectively, reaching maximum.



**Figure 5.** The galvanic current density curve of B10/921A and TA2/921A with different Sc/Sa

Fig.5 showed the galvanic current plots of the TA2/921A and the B10/921A along with the increase of Sc/Sa. The galvanic current of both coupled pairs showed a trend of increase and ultimate value. This experiment result is consistent with what C.M. Abreu [7] researched earlier. That is to say, the galvanic corrosion rate of high potential difference coupling such as TA2/921A and B10/921A showed linear growth with the Sc/Sa. The fitting curves of the galvanic current by both experiments are similar parabolas using the straight-line equation of  $y=0.0009x+0.0274$  ( $R^2=0.9904$ ) and  $y=0.0006x+0.0206$  ( $R^2=0.9906$ ). Accordingly, the effect of cathode/anode area ratio on the galvanic couples was quite large; the galvanic couple with small cathode and large anode is very adverse to the alloy in seawater. This is because of that the corrosion belonged in cathodic oxygen depolarization corrosion in seawater. If corrosion is controlled by the oxygen ionization process, then increasing of cathode area results in the decrease of the ionization potential, and then leading to increase of corrosion rate. If it is controlled by the diffusion of oxygen, cathode area increase means more oxygen reduction reaction occurs, thus the diffusion current increase, lead to the acceleration of anodic dissolution, also cause galvanic corrosion rate to increase.

Analysis of the data in Fig.5 reveals that, the galvanic current density along with the growth of the area ratio is limit, which is different from C.M. Abreu. such as B10/921A and TA2/921A reach limit respectively with Sc/Sa for 500:1 and 400:1. Reason is that the anode polarization increasing and the galvanic current increasing accordingly is due to increase of cathode area. the potential difference reducing gradually caused galvanic current to gradually stabilize, finally no longer to changes with Sc/Sa.

#### 4. Conclusion

The corrosion behavior of B10/921A and TA2/921A has been studied in natural seawater on different cathode/anode area ratio within 240 hours. The paper arrives at the conclusion:

(i)The galvanic corrosion between these alloys is clearly showed, the 921A is the anode, B10 and TA2 are the cathode in galvanic couples B10/921A and TA2/921A.

(ii)The influence of cathode/anode area ratio is a key factor to the rate of galvanic corrosion in seawater. Increasing Sc/Sa accelerated galvanic corrosion rate of high potential difference coupling, The fitting curves of the galvanic current by both experiments are similar parabolas using the straight-line equation of  $y=0.0009x+0.0274$  ( $R^2=0.9904$ ) and  $y=0.0006x+0.0206$  ( $R^2=0.9906$ ).

(iii)Results indicate that the galvanic corrosion rate linear growth with the Sc/Sa in seawater, but had extreme because the galvanic potential shift and driving voltage decreases.

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