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Galvanic Coupling Effect on Corrosion Behavior of Al Alloy-Matrix Composites

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Galvanic coupling effect on the corrosion of SiC-reinforced aluminum alloy-matrix composites was investigated in a sodium chloride solution. The potentiodynamic polarization measurement indicated that pitting potentials of metal matrix composites (MMCs) and AA2124 matrix alloy were similar, and pitting potential of MMCs was almost same as corrosion potential, while pitting susceptibility of MMCs was higher than that of AA2124 alloy. Galvanic current by formation of galvanic couple between SiCw and matrix reveals very low value because of large cathodic polarization of SiC. However, by increasing potential of matrix to pitting potential by this galvanic couple and thus, forming pits easily at the weak passive film near SiC reinforcing phase preferentially, it is concluded that pitting susceptibility of MMCs increases highly than AA2124 alloy of matrix composition.

Key words : Al alloy, SiC, metal matrix composites, galvanic corrosion, pitting

1. INTRODUCTION

Aluminium metal matrix composites (MMCs) have been developed for high performance structural applications due to their high strength, high elasticity and high fatigue and creep resistances. Particularly, SiC-reinforced MMCs offer many advantages in terms of potential mass production at a relatively low cost and in various applications in the aerospace and automotive industries where low density, high strength, and high stiffness are of primary concern.

However, MMCs are composed of materials with different electrochemical properties and thus have problems of low corrosion resistance [1-3]. Since Al, which is an active metal is coupled to such noble reinforcing materials as graphite and SiC, there is a tendency that a galvanic couple is formed between Al and the reinforcing material, which is an inert electrode upon which O_2 and H^+ reduction may occur. Accordingly, several researchers have thought that galvanic corrosion is responsible for the higher corrosion rate observed in graphite or SiC/Al MMCs.

Since the investigation of corrosion behavior and the understanding of the galvanic corrosion mechanism is crucial for enhancement of corrosion resistance and thus utilization of the composite material, there have been many reports on experimental results regarding the corrosion behavior of SiC/Al MMCs. However, there has been no agreement on the effect of galvanic corrosion. Lore and Wolf [4] have been confirming the above galvanic effect in their experiments using SiC/AA6061 MMCs, revealing that the galvanic effect and corrosion behavior increases with the amount of SiC in MMCs. J. F. McIntyre *et al.* [5] have reported that the existence of reinforcing material and thus the formation of galvanic couple could accelerate the formation and the growth of localized corrosion such as pitting. On the contrary, Aylor and Kain [6] and Hihara and Latanision [7] have been reporting that the residual stress caused by SiC rather than the existence of SiC/Al galvanic couple affects the corrosion behavior significantly.

In this study, the pitting susceptibility of MMCs has been evaluated by measuring the pitting potential of SiC-reinforced Al alloy MMCs and it has been measured that the change of galvanic potential and galvanic current by artificial formation of galvanic couple of reinforcing material and matrix alloy. The influence of galvanic couple on pitting corrosion of MMCs has been discussed by analyzing the electrochemical reaction and the correlation between matrix alloy and reinforcing material.

2. EXPERIMENTAL PROCEDURE

In preparation of MMCs, 15 vol.% SiC whiskers (hereinafter 'SiCw') and AA2124 powders were put into an AA6063 can and subsequently degassed. Then, they were hot-pressed with a pressure of about 120 MPa at 520 °C and thus the billet was formed. Finally, it was extruded at an extruding ratio of 20:1 at 470 °C. Although SiCw were rearranged toward the extruded direction, they were not evenly distributed in this MMCs. All electrochemical tests were accomplished on the vertical surface from extruded direction.

For electrochemical testing, a 3.5 wt.% NaCl solution was used at 25 °C, and saturated calomel electrode (SCE) was used for reference electrode. The pitting potential of matrix alloy was measured by dynamic polarization method under a scan speed of 10 mV/min. And the pitting potential in MMCs was measured by the double cycle polarization (DCP) method.

Also, galvanic coupling test between SiCw and matrix alloy was accomplished in order to investigate the effect of coupling on pitting corrosion. Galvanic couple was formed by hot-pressed SiC with 10 mm diameter and 5 mm thickness and AA2124 matrix alloy of same size. Then, galvanic current and galvanic potential were measured by ZRA and electrometer.

3. RESULTS AND DISCUSSION

3.1. Open-circuit potential

Fig. 1 shows the variation of corrosion potential of 15 vol.% SiCw/AA2124 MMCs and AA2124 alloy in 3.5 wt.% NaCl solution. In 2124 matrix alloy, the potential change is vibrating in the beginning but the potential is stabilized to the value of −0.84V (vs. SCE) after an hour. Corrosion potential of MMCs is about −0.67V, which is higher than that (−0.84V) of matrix alloy. Aylor and Moran [8] reported that corrosion potential of MMCs was almost same as that of matrix alloy in SiCw/AA6061 MMCs system, and insisted that the existence of SiC reinforcing material would not influence corrosion potential. However, Trzaskoma *et al.* [9] reported that, while corrosion potential of MMCs and matrix alloy of SiCw/AA5456 were same in 0.1N NaCl solutions, and corrosion potential of MMCs was measured higher than that of matrix alloy in the SiCw/AA6061 MMCs system. Therefore, it is considered that the electrochemical properties including the corrosion potential of MMCs would be dependant on various factors, such as composition of matrix alloy, deaeration/aeration of solution condition, fabrication method, and purity and conductivity of reinforcing material. In this investigation, it is believed that the increase of corrosion potential of SiCw/AA2124 MMCs is attributed to the existence of SiC reinforcing material, and it will be discussed later.

There has been variation in the values of corrosion potential of MMCs during every test, probably due to the non-uniformity of the distribution and content of SiC whiskers on exposed surface. And the continuous variation of open-circuit potential in MMCs is observed, which reveals that the passive film of MMCs is relatively unstable compared with that of matrix alloy.

3.2. Pitting potential

In order to evaluate the pitting susceptibility of MMCs and matrix alloy, pitting potential is measured by dynamic polarization method, and the results are shown in Fig. 2. In matrix alloy, apparent passive region exists by increasing potential from open-circuit state, and pitting potential (−0.69 V), in which current density increased from the polarization curve suddenly, was easily measured. However, in MMCs, passive region does not exist and current density increases rapidly from corrosion potential. It means that pitting is immediately generated from open-circuit condition, as corrosion potential of MMCs is almost same as pitting potential.

Therefore, pitting potential of MMCs is measured by DCP method in this study. Fig. 3 shows the variation of potential-

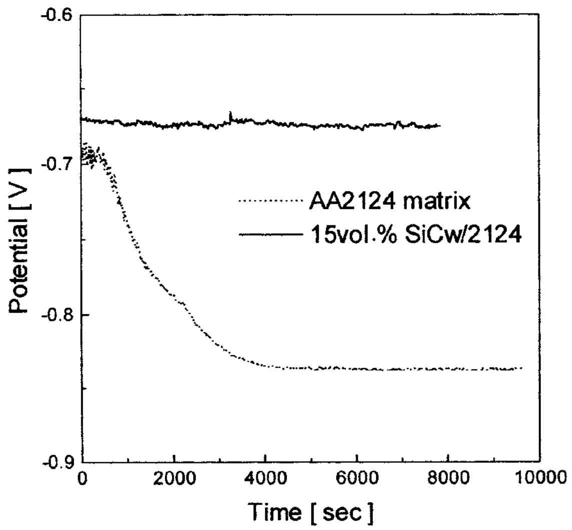


Fig. 1. Variation of open-circuit potential of 15 vol.% SiCw/AA2124 MMCs and AA2124 alloy with time in 3.5 % NaCl solution at 25 °C.

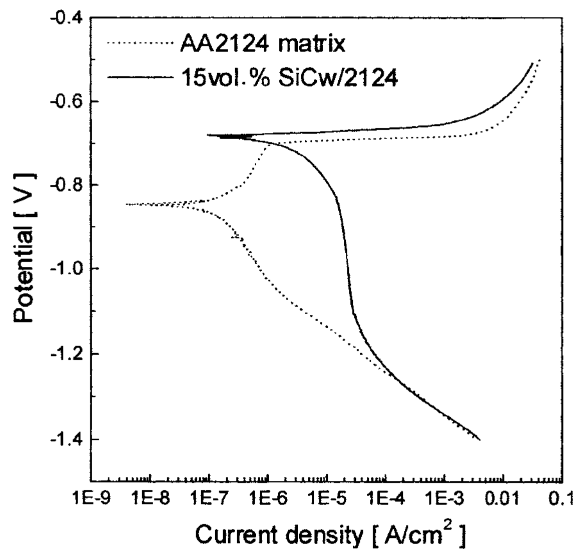
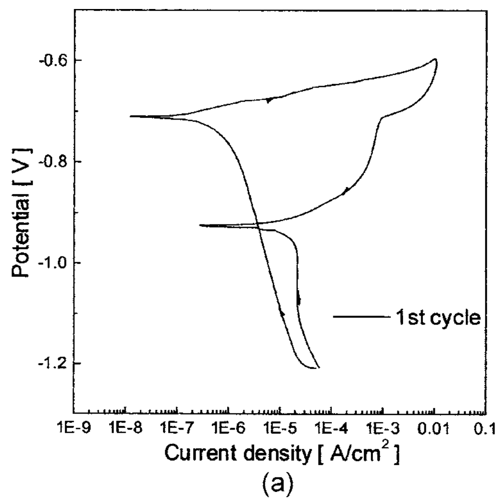


Fig. 2. Anodic and cathodic polarization curves of 15 vol.% SiCw/AA2124 MMCs and AA2124 alloy in 3.5 % NaCl solutions at 25 °C.



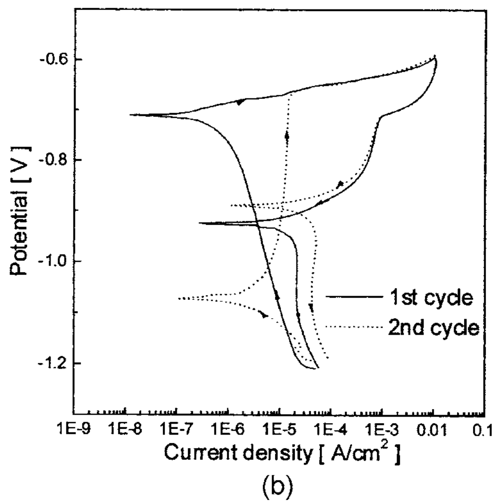


Fig. 3. Cyclic polarization curves of 15 vol.% SiCw /AA2124 MMCs in 3.5 % NaCl solutions: (a) single cyclic polarization; and (b) double cyclic polarization.

current density by DCP method. During the first cycle (Fig. 3(a)), a similar phenomena that current density increases abruptly from corrosion potential appears, however, during the second cycle, apparent passive region exists, and pitting potential where current density increase sharply is measured.

The characteristics, which have been obtained from this experiment by DCP method, can be summarized as follows:

1) The value of corrosion potential in the second cycle is always lower than that in the first cycle.

2) The passive region exists apparently during the second cycle, and pitting potential can be defined.

3) The value of pitting potential measured in the second cycle is almost same as corrosion potential in the first cycle.

Thus the measured pitting potential is −0.69V, and pitting potentials of MMCs and matrix alloy are almost same, revealing that pitting potential of MMCs is not dependant upon the reinforcing material.

Trzaskoma *et al.* [9] reported that pitting potential of SiCw/AA6061 was similar to matrix alloy's. They concluded that the pitting resistance of passive film on the surface of aluminum matrix was seldomly affected by existence of SiC. The pitting potential of SiCw/AA2124 measured in this study also agree with Trzaskoma *et al.*'s data. Even though there is no variation of pitting resistance in passive film itself as postulated by Trzaskoma *et al.*, pitting can be occurred immediately from open-circuit condition because corrosion potential of SiCw/AA2124 MMCs increases higher than matrix alloy and approaches to pitting potential. Hence it is concluded that pitting susceptibility of MMCs would be higher than AA2124 matrix alloy.

3.3. Galvanic coupling effect

Since MMCs have junctions of two electrochemically dissimilar materials, the galvanic corrosion between the matrix alloy and the reinforcing material degrades the corrosion resistance. As inert reinforcing materials such as graphite, SiC, and TiB_2 have a higher electrode potential than matrix alloy, they can reduce H_2 and O_2. Accordingly, the corrosion of matrix alloy is accelerated by the formation of galvanic couple with the reinforcing material of sufficient electric conductivity. Since it is very difficult to conduct the electrochemical tests using SiCw, a hot-pressed SiC has been used in order to reveal the galvanic corrosion mechanism between the SiCw reinforcing material and alloy matrix. An artificial galvanic couple with the hot-pressed SiC has been formed and the galvanic current and galvanic potential have been measured, and then, the mixed potential theory has been applied.

Fig. 4 shows a cathodic polarization curve of SiC reinforcing material and anodic polarization curves of matrix alloy

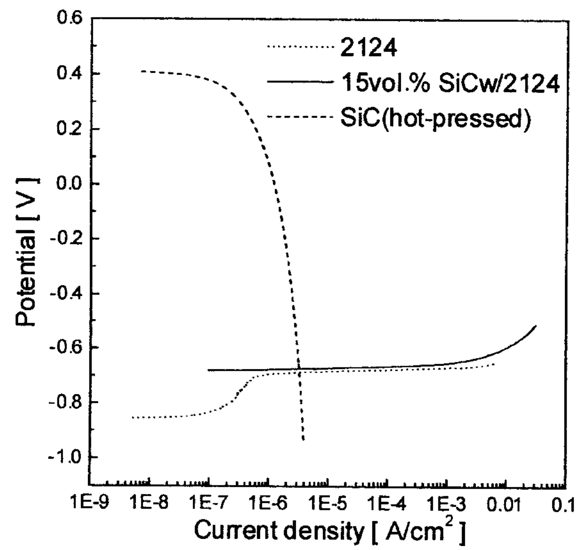


Fig. 4. Cathodic polarization curve of hot-pressed SiC and anodic polarization curves of 15 vol.% SiCw/AA2124 MMCs and AA2124 alloy in 3.5 % NaCl solutions.

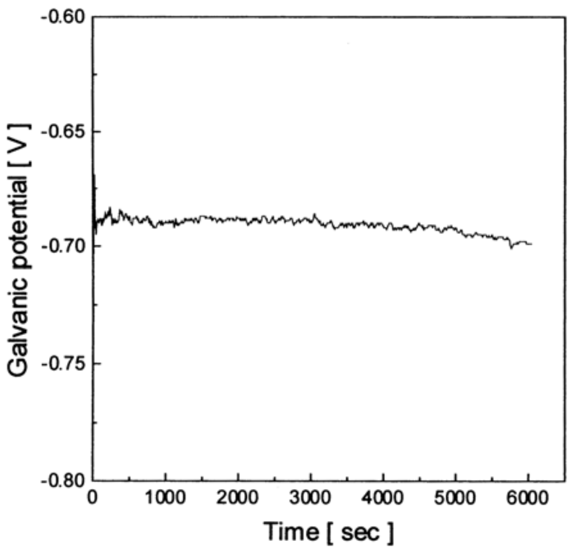


Fig. 5. Variation of galvanic potential of a SiC-AA2124 galvanic couple with time in a 3.5 % NaCl solution.

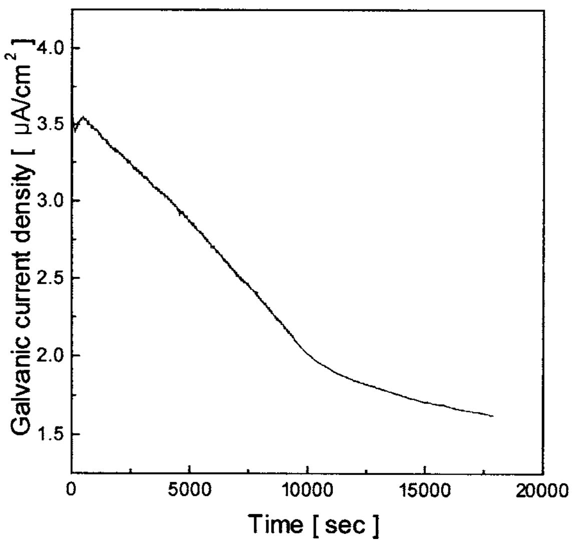


Fig. 6. Variation of galvanic current density of a SiC-AA2124 galvanic couple with time in a 3.5 % NaCl solution.

and MMCs. By analyzing the galvanic coupling effect of MMCs through an application of Fig. 4 to mixed potential theory, galvanic current density reveals very low value because of large cathodic polarization of SiC. However, galvanic potential has higher value than corrosion potential of matrix alloy and approaches to corrosion potential of MMCs. This means that the increase of matrix alloy potential is caused by SiC reinforcing material.

Galvanic potential and galvanic current density of SiC-AA2124 galvanic couple are measured, and the results are shown in Figs. 5 and 6. As the above interpretation of mixed potential theory, galvanic current density was measured by a few $\mu A/cm^2$, and the effect of galvanic couple on corrosion rate seems to be almost negligible. And galvanic potential is measured by −0.69 V, whose value is very close to pitting potential.

Lore and Wolf [4] reported that corrosion rate of SiC/AA6061 increased in proportion to the content of SiC, and the phenomenon was caused by galvanic corrosion between SiC and matrix alloy. However, Aylor and Kain [5], and Hihara and Latanision [6] insisted that galvanic couple of SiC/Al did not affect the corrosion rate seriously. The result of this experiment shows that the very low value of galvanic current was obtained as in the result of Aylor and Hihara, and there is almost no direct effect on corrosion rate by galvanic current.

On the other hand, potential of matrix alloy increased highly and approached to pitting potential indicating that pitting can occurs easily on open-circuit state in MMCs. Therefore, the reason that pitting susceptibility of MMCs increases higher than AA2124 alloy of matrix composition can be explained as the potential elevating effect by galvanic coupling.

In conclusion, corrosion potential of MMCs shows higher value than AA2124 matrix alloy by the formation of galvanic couple between SiCw and matrix. Also, potential of matrix increases to pitting potential by this effect and pitting occurs easily at the weak passive film near SiC reinforcing phase. Therefore it is concluded that pitting susceptibility of MMCs increases highly than AA2124 alloy of matrix composition.

4. CONCLUSIONS

The corrosion potential and pitting potential of 15 vol.% SiCw/2124 MMCs have been measured and the galvanic corrosion tests between SiC reinforcing material and AA2124 matrix alloy have been performed in 3.5 % NaCl solutions, and the conclusions are as follows.

1) Corrosion potential of MMCs exhibits −0.67 V, which is higher than that of AA2124 matrix alloy (−0.84 V), because of galvanic coupling effect between SiCw and matrix.

2) Pitting potentials of MMCs and matrix alloy are obtained by −0.69V of equivalent value. It means that there is no variation of pitting resistance of passive film itself on the surface of MMCs by the existence of SiC reinforcing materials. However, pitting potential of MMCs is almost same as corrosion potential, and pitting susceptibility of MMCs is higher than that of matrix alloy.

3) Galvanic current by formation of galvanic couple between SiCw and matrix reveals very low value because of large cathodic polarization of SiC. However, by increasing potential of matrix to pitting potential by this galvanic couple and thus, forming pits easily at the weak passive film near SiC reinforcing phase preferentially, it is concluded that pitting susceptibility of MMCs increases highly than AA2124 alloy of matrix composition.

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