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Corrosion Inhibition Of T-6 Treated 6061 Al–SiC$_{(p)}$ Composite In Hydrochloric Acid

J. Nayak and K.R. Hebbar
Department of Metallurgical and Materials Engineering
National Institute of Technology Karnataka, Surathkal-575 025, India
Email:jaganmet@gmail.com
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ABSTRACT

Addition of reinforcements like SiC to aluminium matrix has been reported to decrease the corrosion resistance of the matrix due to several reasons, one of them being the galvanic action between the reinforcement and the matrix. Aging of aluminium alloys can also have similar effects as aging results in precipitation of intermetallics. The work deals with effect of aging (T-6 treatment) on the corrosion behaviour as well as corrosion inhibition of 6061Al-SiC composite. Corrosion behaviour of 6061 Al–SiC$_{(p)}$ composite were determined in HCl by Tafel extrapolation technique in the temperature range of 30ºC-50ºC. Further, the inhibition studies were made using two inhibitors viz. (i) Allyl Thiourea and (ii) Glycyl Glycine. The results indicate that both the organic compounds act as anodic inhibitors and are moderately effective in inhibiting the corrosion of 6061Al–SiC$_{(p)}$ composite. The inhibition efficiency increases with increase in inhibitor concentration. Similar inhibition studies were made on the aged samples. However, in the case of T-6 treated samples, the inhibition efficiency was found to be poor compared to the non-heat treated samples.

1. INTRODUCTION

Aluminium matrix composites possess high Young's modulus/density and yield strength/density ratios together with tailorable coefficient of thermal expansion and high thermal stability as well as conductivity and hence look very promising and find applications in aerospace, military and automobile industries[1-5]. However, one of the main drawbacks of aluminium matrix composites is the decrease in corrosion resistance compared to the base alloy. Base alloys inherently develop a protective oxide surface film which imparts corrosion resistance; but, addition of reinforcing phase (mainly its proportion and particle size) leads to inhomogeneities and can cause discontinuities in the surface film, increasing the number of sites where corrosion can be initiated and making the composite more vulnerable to corrosion attack[2,6-9]. In these cases, the galvanic action between the reinforcement and the matrix will stimulate the corrosion process of the matrix. Aging of these composites may aggravate the problem as aging induces additional heterogeneities in the form of precipitates and matrix strain. It is, therefore, very important to add corrosion inhibitors to decrease the corrosion rate of Al composites. A wide variety of compounds are reported as inhibitors and these are mainly organic compounds usually containing N, S or O atoms[10-13].

The present work deals with the inhibitive action of (i) Allyl Thiourea and (ii) Glycyl Glycine on the corrosion behaviour of T-6 treated 6061Al-15vol% SiC$_{(P)}$ composite in 0.01N, 0.1N and 1N HCl solutions with four levels of concentrations of each inhibitor. Potentiodynamic studies are carried out to establish the corrosion inhibition by the above compounds.

2. EXPERIMENTAL

2.1 Material

The 6061Al-SiC composites (with 15 vol% SiC particles of size 23 µm, irregular shape) were cast in the form of 10 cylinders each of 90 mm diameter and 240 mm height by stir casting technique at RRL, Thiruvananthapuram. These cylinders were extruded at 430-480ºC with extrusion ratio of 30:1 [two rods each of 11.5 mm diameter] at Servel Engineers, Mangalore. These extruded rods were cut into required size and corrosion studies were made. The Composition of base metal 6061 Al alloy is given in Table 1. The microstructure of the composite material used is shown in Fig. 1. The extruded rods were subjected to T-6 treatment. The samples were solutionized at 350ºC for an hour and quenched in water. The samples were then aged at 180ºC for different durations of time followed by water quenching. The under-aged, peak-aged and over-aged samples were identified from the aging curves.

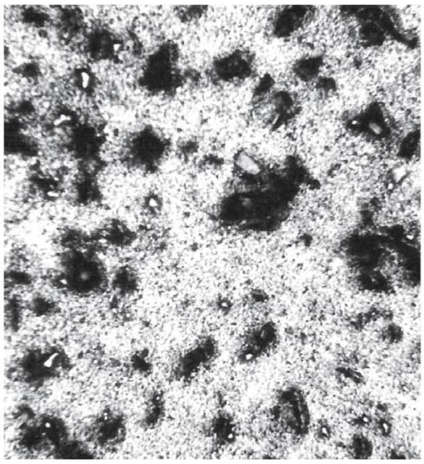

Fig. 1 : Microstructure of 6061Al-15%SiC composite
Etchant : Kellar's reagent Mag:100X

Table 1

Nominal chemical composition of base metal (6061 Al alloy)

Element	Cu	Mg	Si	Cr	Al
Wt. Pct.	0.25	1.0	0.6	0.25	Balance

2.2 Medium

Test solutions of 0.01, 0.1 and 1N HCl were made using AR grade hydrochloric acid (Merck) and distilled water.

2.3 Inhibitors

(i) Allyl Thiourea (mol. Wt. 102) and (ii) Glycyl Glycine (mol. Wt. 132.12) were used as inhibitors.

2.4 Method

Tafel polarization studies were carried out by using a potentiostat (CH Instruments, USA Model 604A) and a 3–electrode cell. An area of 1.04 cm^2 of the polished Al–SiC composite specimens (without T-6 treatment) was exposed to 250 ml of acid solution (0.01, 0.1, 1.0 N) at 30°C without and with (i) 50 (ii) 100 (iii) 200 and (iv) 500 ppm inhibitors in the acid solution. The polarization studies were made from –250mV to +250 mV against open circuit potential(OCP) with a scan rate of 20mV per minute and the corresponding corrosion currents, *i,* recorded. From potential (E) Vs log *i* plot, corrosion potential (E_{corr}) and corrosion current (i_{corr}) were determined. The corrosion rate (C.R.), in mpy, is calculated using the relation:

C.R.(mpy) = 0.129 x i_{corr} x $(\text{Equivalent weight/density})_{composite}$ =0.4051x i_{corr} where i_{corr} is current density in $\mu A.cm^{-2}$.

The surface coverage θ is calculated as

$$\theta = \frac{i_{corr(uninh)} - i_{corr(ih)}}{i_{corr(uninh)}}$$

The percentage inhibition efficiency (%IE) = θ x 100

The experiments were repeated for 40°C and 50°C and E_{corr}, i_{corr}, C.R., θ and % IE were determined.

Table 2

Corrosion rates of T-6 treated 6061Al-15%SiC composite

Medium	Corrosion Rate, mpy				
	Temp.	Without T-6	Under-aged	Peak-aged	Over-aged
1 N HCl	30°C	5495	5722	6420	5592
	40°C	7204	7719	8083	7372
	50°C	9069	9388	9718	9280
0.1 N HCl	30°C	72	128	161	81
	40°C	161	203	223	173
	50°C	256	287	361	281
0.01 N HCl	30°C	7	10	13	8
	40°C	13	16	22	13
	50°C	26	32	42	26

Table 3a

Corrosion Rates of 6061 Al- 15%SiC Composite and % Inhibition Efficiency

Inhibitor: Allyl Thiourea

Medium	Temp	Corrosion Rate, mpy (% Inhibition Efficiency)				
		Inhibitor Concentration				
		0 ppm	50 ppm	100 ppm	200 ppm	500 ppm
1 N HCl	30^0 C	5495	3851 (30.0%)	3218 (41.4%)	2556 (53.4%)	2278 (58.5%)
	40^0 C	7204	5100 (29.2%)	4402 (38.8%)	3610 (49.8%)	3218 (55.3%)
	50^0 C	9069	6918 (23.7%)	5680 (37.3%)	4897 (46.0%)	4677 (48.4%)
0.1N HCl	30^0 C	72	36 (50.0%)	30 (58.3%)	21 (70.8%)	17 (76.3%)
	40^0 C	161	102 (36.6%)	81 (49.6%)	61 (68.3%)	40 (75.1%)
	50^0 C	256	181 (29.2%)	161 (37.1%)	114 (55.4%)	102 (60.1%)
0.01 HCl	30^0 C	7	3 (57.1%)	3 (57.1%)	2 (71.4%)	2 (71.4%)
	40^0 C	13	11 (15.3%)	8 (38.4%)	7 (46.1%)	6 (53.3%)
	50^0 C	26	23 (11.5%)	20 (23.05)	18 (30.8%)	16 (38.4%)

Table 3b

Corrosion Rates of 6061 Al- 15%SiC Composite and % Inhibition Efficiency
Inhibitor: Glycyl Glycine

Medium	Temp	Corrosion Rate, mpy (% Inhibition Efficiency)				
		Inhibitor Concentration				
		0 ppm	50 ppm	100 ppm	200 ppm	500 ppm
1 N HCl	30^0 C	5495	40.51(26.3%)	3610(34.3%)	3217(41.4%)	30.1(44.3%)
	40^0 C	7204	5086(29.4%)	4602(36.1%)	3745(48.1%)	3610(49.9%)
	50^0 C	9069	6100(43.8%)	5545(49.9%)	5218(64.5%)	5078(74.9%)
0.1N HCl	30^0 C	72	66(8.3%)	57(20.8%)	51(29.2%)	37(48.6%)
	40^0 C	161	102(36.6%)	91(43.5%)	74(54.0%)	41(74.5%)
	50^0 C	256	104(59.3%)	92(64.1%)	87(66.0%)	64(75.0%)
0.01 HCl	30^0 C	7	5(28.6%)	4(42.9%)	3(57.1%)	2(71.4%)
	40^0 C	13	8(38.5%)	5(61.5%)	4(69.2%)	3(76.9%)
	50^0 C	26	9(65.4%)	8(69.2%)	6(76.9%)	4(84.6%)

Table 4a

Effect of T-6 treatment on the Corrosion Rates and % Inhibition Efficiency of 6061Al-15%SiC composites at 30°C.
Inhibitor: Allyl Thiourea

Medium	Material Condition	Corrosion Rate (% Inhibition Efficiency)				
		Inhibitor Concentration				
		0 ppm	50 ppm	100 ppm	200 ppm	500 ppm
1N HCl	Without T6	5495 (0)	3851(30.0)	3218 (41.4)	2556 (53.4)	2278 (58.5)
	Under-Aged	5722 (0)	4234 (26.1)	3593 (37.2)	2952 (48.4)	2712 (52.6)
	Peak-Aged	6420 (0)	4930 (23.2)	4250 (33.8)	3582 (44.2)	3332 (48.1)
	Over-Aged	5592 (0)	4222 (24.5)	3562 (36.3)	2997 (46.4)	1118 (49.5)
0.1N HCl	Without T6	72 (0)	36 (50.0)	30 (58.3)	21 (70.8)	17 (76.3)
	Under-Aged	128 (0)	72 (43.5)	61 (52.2)	49 (61.8)	41 (67.9)
	Peak-Aged	161 (0)	99 (38.4)	86 (46.3)	71 (56.2)	58 (63.5)
	Over-Aged	81 (0)	48 (41.2)	42 (47.8)	34 (58.2)	28 (65.1)
0.01N HCl	Without T6	7 (0)	3 (57.1)	3 (57.1)	2 (71.4)	2 (71.4)
	Under-Aged	10 (0)	5 (50.0)	4 (60.0)	3 (70.0)	3 (70.0)
	Peak-Aged	13 (0)	7 (46.1)	6.5 (50.0)	5 (61.5)	4 (69.2)
	Over-Aged	8 (0)	4.5 (43.7)	4 (50.0)	3.5 (56.0)	3 (62.5)

Similar inhibitor studies were made on T-6 treated samples at 30°C.

3. RESULTS AND DISCUSSION

Average values of corrosion rates obtained for various experimental conditions are tabulated in Tables 2, 3a and 3b. The results indicate that the composite is highly susceptible to corrosion in 1N HCl while its corrosion rate is very low in 0.01N HCl even at 50°C. Corrosion rate of the composite increases with increase in temperature. Presence of inhibitors brings down the corrosion rate considerably, the rate being lowest at the highest (500ppm) concentration of the inhibitors.

Both the inhibitors, Allyl Thiourea and Glycyl Glycine are fairly effective in bringing down the corrosion rate. Inhibition efficiency increases with increase in the inhibitor concentration at all temperatures and in all the media. In case of Allyl Thiourea, the inhibition efficiency decreases with increasing temperature suggesting that the adsorption is of physisorption type. A maximum inhibition efficiency of about 76% could be achieved with 500 ppm of inhibitor addition in 0.1N HCl at 30°C. However, in case of Glycyl Glycine, the inhibition efficiency increases with increasing temperature suggesting that the adsorption is of chemisorption type. A maximum inhibition efficiency of about 84% could be achieved with 500 ppm of inhibitor in 0.01N HCl at 50°C.

The aging treatment was found to have influence on the corrosion rate as the T-6 treated samples showed higher corrosion rates as compared to the non-treated samples under similar experimental conditions (Tables 4a and 4b). This higher corrosion rates of aged samples are attributed to two

Table 4b

Effect of T-6 treatment on the Corrosion Rates and % Inhibition Efficiency of 6061Al-15%SiC composites at 30°C. Inhibitor: Glycyl Glycine

Medium	Material Condition	Corrosion Rate (% Inhibition Efficiency)				
		Inhibitor Concentration				
		0 ppm	50 ppm	100 ppm	200 ppm	500 ppm
1N HCl	Without T6	5495 (0)	4051(26.3)	3610 (34.3)	3217 (41.4)	3010 (44.3)
	Under-Aged	5722 (0)	4405 (23.0)	4120 (27.9)	3663 (36.1)	3490 (38.9)
	Peak-Aged	6420 (0)	5072 (20.9)	4751 (26.1)	4366 (32.4)	4237 (34.2)
	Over-Aged	5592 (0)	4362 (22.0)	4082 (27.1)	3635 (35.3)	3578 36.1)
0.1N HCl	Without T6	72 (0)	66 (8.3)	57 (20.8)	51 (29.2)	37 (48.6)
	Under-Aged	128 (0)	118 (7.8)	105 (18.0)	94 (26.2)	82 (35.9)
	Peak-Aged	161 (0)	151 (6.2)	135 (16.2)	125 (22.3)	109 (32.3)
	Over-Aged	81 (0)	75 (7.4)	67 (17.3)	61 (24.6)	52 (35.8)
0.01N HCl	Without T6	7 (0)	5 (28.6)	4 (42.9)	3 (57.1)	2 (71.4)
	Under-Aged	10 (0)	7.4 (26)	6.2 (38)	4.8 (52)	3.2 (68)
	Peak-Aged	13 (0)	10.3 (20.7)	8.8 (32.3)	7.0 (46.1)	5.7 (56.2)
	Over-Aged	8 (0)	6.2 (22.5)	5.3 (33.7)	4.2 (47.5)	3.0 (62.5)

parameters; (i) presence of intermetallic precipitates which are anodic to the matrix causing galvanic effect and (ii) the matrix strain arising due to age-hardening effect. Among the aged specimens, the peak-aged samples show the highest corrosion as the above effects are maximum in these samples. Over-aging causes coarsening of precipitates thereby reducing the interfacial area between the matrix and the precipitate. It also reduces the matrix strain due to incoherency. Thus, these samples show lower corrosion rates.

Inhibition efficiency was poor in aged samples. The inhibitors that are added are essentially adsorption type inhibitors where the inhibitor molecules get adsorbed on to the metal surface through their polar ends and spread like an umbrella thereby covering the metal surface. Precipitation of intermetallics reduces the number of adsorption sites and hence the efficiency comes down. Since the peak-aged samples are expected to have maximum number of precipitates, the inhibition efficiency is poor compared to either under-aged or over-aged samples.

4. CONCLUSIONS

(i) 6061Al-SiC composite is highly susceptible to corrosion in 1N HCl

(ii) Both the inhibitors are moderately effective in inhibiting the corrosion of 6061Al–SiC composites in HCl environment.

(iii) The inhibition efficiency increases with inhibitor concentration for a given set of conditions for both the inhibitors.

(iv) T-6 treatment enhances the corrosion rates. Among the aged samples, peak-aged samples show highest corrosion rates followed by over-aged and under-aged samples.

(v) Inhibition efficiency was found to be poor for aged samples.

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