JCSE The Journal of Corrosion Science and Engineering
ISSN 1466-8858 Volume 16, Preprint 36 submitted 17 May 2013

Inhibitive action of potassium iodide on the corrosion of stir-cast Al-Si/SiC in NaCl-KI interface

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ABSTRACT

The inhibitive action of potassium iodide (KI) on the corrosion of Al-Si/SiC particulate composite in 3.65% NaCl solution was investigated using gravimetric and potentiodynamic polarization techniques at 298K. The results showed that KI in NaCl-aluminium alloy/SiC composite environment decreased the corrosion rate at all concentrations considered. Inhibitor efficiencies (IE) of 97.17, 97.34 and 97.57% with 0.5 g/v addition using gravimetric method were achieved at 92, 196 and 288 h of exposure time respectively. The IE from the potentiodynamic polarization method in both conditions was significantly enhanced. The high resolution scanning electron microscope (HRSEM) for surface morphology of as-corroded uninhibited condition showed pits and cracks formation than as-corroded inhibited condition. The additions of KI as corrosion inhibitor indicates a higher potential value, IE and polarization resistance with decreased in current density. The two methods employed for the corrosion assessment of the composite was in agreement and mixed-type corrosion exists which followed Langmuir adsorption isotherms.

***Keywords*: Al-Si/SiC composite, inhibitor efficiency, thin film, interface**

1. Introduction

Metal matrix composite (MMCs) as a new generation of materials found wide range of industrial application in aerospace and automobile [1]. In these materials, a reinforcement usually ceramics are incorporated to obtain an excellent properties; such as specific stiffness, high elastic modulus, wear resistance [2,3]. Among the MMCs, aluminium matrix composites (AMCs) are gaining considerable amount of industrial importance because of their excellent combination of physical, mechanical and electrochemical properties. Due to their interesting combination of properties, these materials are being used in many engineering applications such as automobile; pistons, track shoes, brake drums, cylinder liners [4], marine [5,6], mining and mineral processing applications [7,8].

One of the major limitations of AMCs has been low corrosion resistance in aqueous environment. Several researches have been carried out extensively on the corrosion of AMCs and common reinforcements such as SiC and Al_2O_3. Fang et al. [9] studied the synergistic effect of wear and corrosion on Al_2O_3 particulate reinforced 6061 aluminium matrix composite, and reported that reinforcement was detrimental to the corrosion resistance of the aluminium metal matrix. Based on the work reported by Saraswathi et al [5] on the corrosion behaviour of Al-Si/SiC composite in three different media, namely synthetic mine water, 3.5%NaCl solution and 3.5% NaOH solution through immersion technique, and reported that the corrosion rate in 3.5%NaCl solution was minimum followed by synthetic mine water while that of 3.5% NaOH solution was the highest.

In their work, the use of inhibitor was not considered. However, the requirements needed from this composite are still insufficient in an aggressive-corrosion service condition [10]. Hence, methods for enhancing these limitations become necessary. Since corrosion prevention has been area of focus among researchers because of the aforementioned application of the composite. Although over the years, various methods have been put forward to address this limitation [11,12]. One of the methods of combating and controlling corrosion in aqueous environment is the application of corrosion inhibitors [13,14]. Asuke et al., [11] studied the corrosion inhibition of Al-Si/SiC composite with palm wine as inhibitor using gravimetric technique. They reported a maximum inhibition efficiency of 47.63% at 30^{o}C with optimum concentration of 1.0% v/v. In the present study the corrosion inhibition of Al-Si/SiC composite in 3.65% NaCl-KI interface have been investigated using gravimetric and potentiodynamic polarization techniques.

2. Experimental procedures

2.1 Materials and sample preparation

A stir-cast aluminium composite specimen of dimension 20 x 20 x 3 mm as-received with chemical composition of 5%Si, 15%SiC and 80%Al was used as coupons for the corrosion study in 3.65%NaCl solution. Initially, the coupons were mechanically polished with emery papers from 600 down to 1000 grit. The samples were degreased in ethanol, dried, weighed and stored in a desiccator. The initial weight of each sample was taken and recorded. Corrosion studies were conducted at room temperature (298K).

2.2 Gravimetric measurement (GM)

The gravimetric corrosion test was carried out on the previous weighed samples with and without inhibitor at 298K. The volume of the NaCl solution was 100 mL with and without the addition of potassium iodide (KI) inhibitor. The KI inhibitor concentration was varied from 0.5, 1.0, 1.5 and 2.0 g/v in 100 ml of 3.65g of NaCl solution. For each sample, using gravimetric method, the samples were washed, dried and weight taken at interval of 96, 192 and 288 h of exposure time. The corrosion rate and inhibitor efficiency were determined along with the degree of surface coverage for each inhibitor concentration at 298K.

2.3 Electrochemical measurement

The potentiodynamic polarization (PP) and linear polarization resistance was used to study the corrosion inhibition of the Al-Si/SiC composite in NaCl solution. In the electrochemical test, a glass corrosion cell kit with a platinum counter electrode, a saturated Ag/Ag reference electrode and Al-Si/SiC composite sample as working were used. The working electrodes samples were positioned at the glass corrosion cell kit, leaving 1 cm^2 surfaces in contact with the solution. Polarization test were carried out in a solution consisting of 3.65%NaCl solution at room temperature using a potentiostat. The polarization curves were determined by stepping the potential at a scan rate of 0.003V/sec. The corrosion rate and potential were estimated by the Tafel extrapolation method using both the anodic and cathodic branches of the polarization curves.

2.4 Surface morphology

The surface morphology of as-corroded uninhibited and inhibited aluminium sample was observed with high resolution scanning electron microscopy (model: Joel JSM 7600F).

3. Results and discussion

3.1 Results

The results obtained from the gravimetric corrosion evaluation for the aluminium alloy composite in 3.65% NaCl solution along with the variation in inhibitor concentration can be found in Table 1 and Figure 1. Table 2 shows the electrochemical corrosion data obtained for aluminium alloy composite-3.65% NaCl/KI interface. Figure 2, indicates the polarization curves for the composite. The Micrographs of the surface morphology of as-corroded uninhibited/inhibited composite in 3.65% NaCl/KI condition are presented in Figures 3 and 4. Percentage inhibitor efficiency (%IE) using different methods for corrosion assessment can be found in Figure 5. While in Figure 6, the Langmuir adsorption isotherms for the environmental condition have been demonstrated.

3.2 Discussion

3.2.1 Gravimetric measurement

Potassium iodide (KI) was used for the study of mild steel-HCl corrosion behavior with different inhibitor concentrations at 298K. In each concentration, the corrosion rate (mm/yr) was calculated and the inhibitor efficiency IE (%) was determined using equation (1) and (2) below;

$$CR = \frac{Wo - Wa}{At} \qquad (1)$$

$$IE\ (\%) = \frac{(CRa - CRp)100}{CRa} \qquad (2)$$

Where Wo and Wa are the specimen weight before and after immersion in the tested solution, A is the area of the mild steel specimen and t is the exposure time (hr). CRa and CRp are the corrosion rate in the absence and present of inhibitor respectively

A 3.65% NaCl solution was used as an environment to study the corrosion inhibition of Al-Si/SiC at 298K. Results show that corrosion rate (CR) of the composite decreased with addition of KI corrosion inhibitor and exposure time of 96, 192, 288 h (Tables 1, Figure 2).

At the interface and various exposure times, corrosion rate decreased throughout with excellent percentage inhibitor efficiency (% IE). Specifically, Figure 2 shows a decreased in corrosion rate with concentration of inhibitor for all the immersion time at 298K. Considering an exposure time of 96 h, higher % IE was calculated to be 97.17% at 0.5 g/v KI addition. While at 0.5 g/v inhibitor concentration for 192 and 288 h exposure time, corrosion rate/IE were found to be 0.0952/97.34% and 0.0067/97.57% respectively. However, corrosion resistance of aluminium composite in 0.5 g/v KI is higher than those obtainable at other concentrations. This behaviour have been attributed to the formation of thin oxides as evidenced in the EDS (Figures 4) which interfere with the anodic and cathodic reaction.

Therefore formation of pits and their growths becomes difficult. The thin layer of the oxides adheres to the metal surface resulting into a decreased in the corrosion rate.

Table 1

Corrosion rate (CR), Inhibition efficiency and surface coverage (θ) for Al-Si/SiC in 3.65%NaCl solution without and with varying concentration of KI obtained from gravimetric technique at 298K.

Exposure time (h)	Concentration of inhibitor (g/v)	CR 0.5M NaCl (mm/day)	Surface coverage (θ) for NaCl	Inhibition Efficiency (%) for NaCl
96	0	1.0219	-------	-------
	0.5	0.0185	0.9717	97.17
	1.0	0.0346	0.9551	95.51
	1.5	0.0453	0.9262	92.62
	2.0	0.3192	0.5931	59.31
	0	0.5565	-------	-------
192	0.5	0.0952	0.9734	97.34
	1.0	0.0176	0.9575	95.75
	1.5	0.0303	0.9291	92.91
	2.0	0.1719	0.5981	59.81
288	0	0.3220	-------	-------
	0.5	0.0067	0.9757	97.57
	1.0	0.0120	0.9624	96.24
	1.5	0.0165	0.9352	93.52
	2.0	0.1149	0.6438	64.38

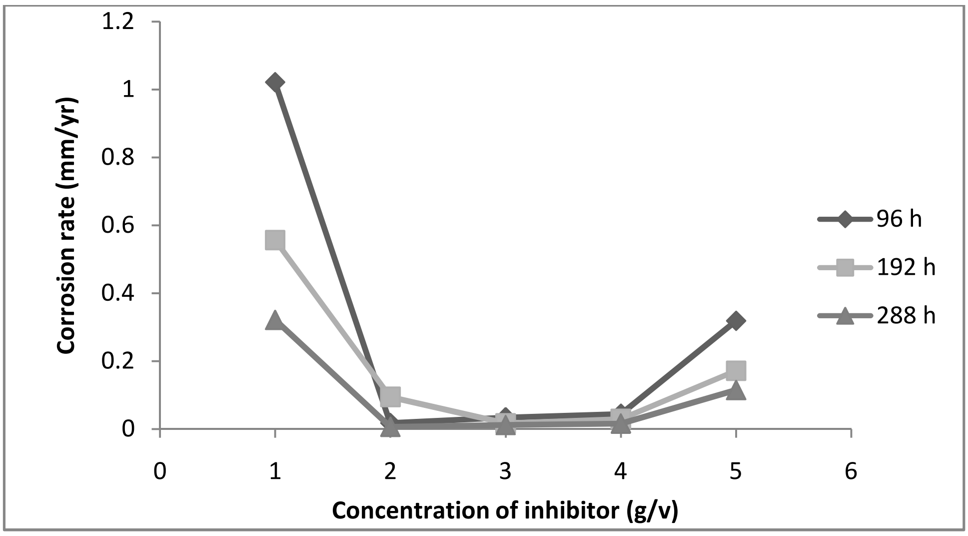

Fig. 1. Variation of corrosion rate with concentration of inhibitor for aluminium in 3.65% NaCl without and with varying concentration of KI at 298K.

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3.2.2 Potentiodynamic polarization

From the potentiodynamic measurement for Al-Si/SiC composite (Table 2), potentiodynamic polarization-corrosion rate (PP-CR), potentiodynamic polarization-corrosion density (PP-I_{corr}), and linear polarization resistance (LPR) were used as criteria for evaluation of corrosion resistance of aluminium composite in the environment. Figure 2 indicate the polarization curves for Al-Si/SiC at 298K. In general, the composite demonstrated a decreased corrosion rate and current density with addition of KI inhibitor at all concentrations. While the corrosion potential (E_{corr}) and polarization resistance (R_p) increases with inhibitor concentrations. This is in agreement with previous studies [15]. The inhibited composite showed that corrosion rate decreased from 2.14E-03 mm/yr to 7.70E-08, 6.66E-07, 8.64E-07 and 1.727E-03 mm/yr at 0.5, 1.0, 1.5 and 2.0 KI additions respectively. It is important to note that corrosion resistance of Al-Si/SiC-NaCl-0.5g/v KI interface is much higher than other interfaces with IE of 99.99% obtained at 0.5 g/v KI addition for PP and 95.57% at 188 h for GM. Similar result was reported [15]. However, based on the changes in anodic and cathodic branches for both environments, the inhibitor is believed to be mixed-type.

Table 2

Electrochemical corrosion data obtained for Al-Si/SiC in 3.65% NaCl solution without and with varying concentration of KI obtained from polarization technique at 298K.

S/N	C (g/v)	I_{corr} (A/cm^2)	b_a (v/dec)	LPR R_p (Ωcm^2)	$-E_{corr}$ (V)	CR (mm/yr)
1	0	8.83E-07	0.15529	2.60E+04	1.2293	2.14E-03
2	0.5	3.17E-11	0.33916	1.11E+09	0.75272	7.70E-08
3	1.0	2.75E-10	2.3665	1.06E+09	0.75272	6.66E-07
4	1.5	3.57E-10	1.5361	5.41E+08	0.62152	8.64E-07
5	2.0	7.12E-07	-0.3249	5.58E+05	1.2293	1.727E-03

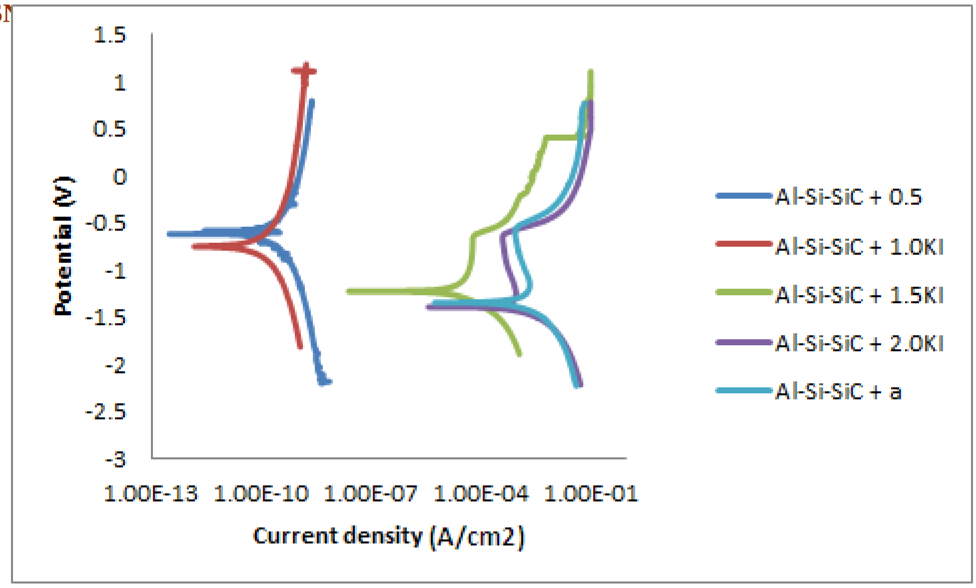

Fig. 2. Linear polarization of Al-Si/SiC in 3.65% NaCl solution without and with varying concentration of KI from gravimetric technique at 298K.

3.2.3 Scanning electron microscope-Energy dispersive spectroscopy (SEM-EDS)

The surface morphology of uninhibited aluminium composite (see Figure 3) shown severe pits, cracks and selective dissolution of intermetallic occurred at the surface as compared with Figure 4 indicating that there was an improvement in the surface morphology of composite that was treated with the inhibitor, which correspond to the lower corrosion rate obtained from the linear polarization analysis. The microstructure of the inhibited do not revealed severe pits and cracks.

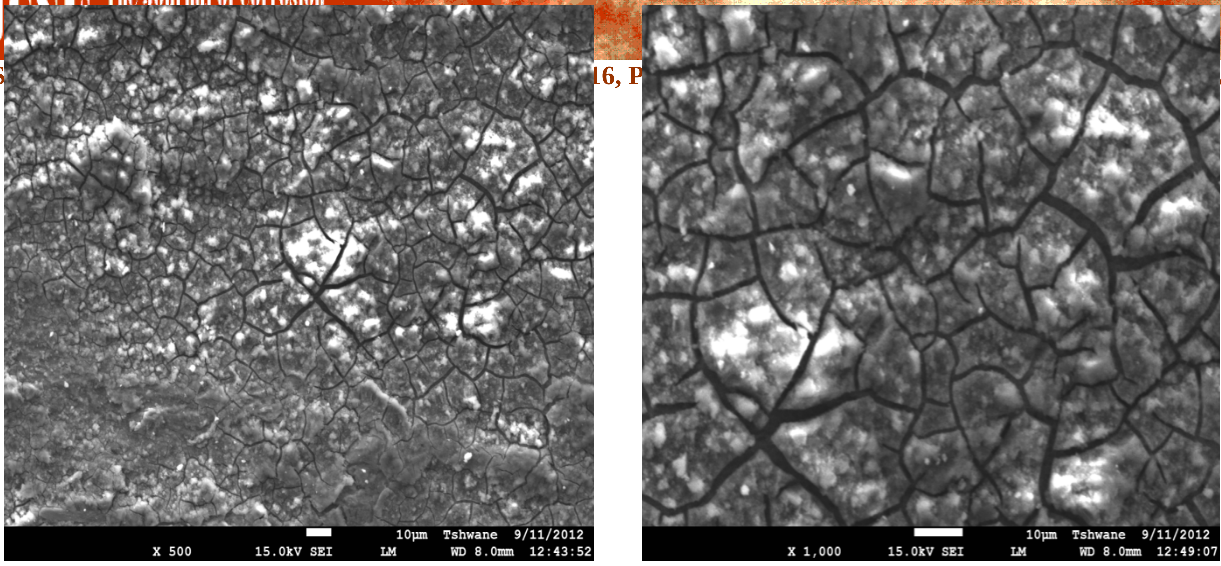

Fig. 3. SEM micrograph of uninhibited Al-Si/SiC in 3.65% NaCl solution after 288 h of exposure at different magnifications.

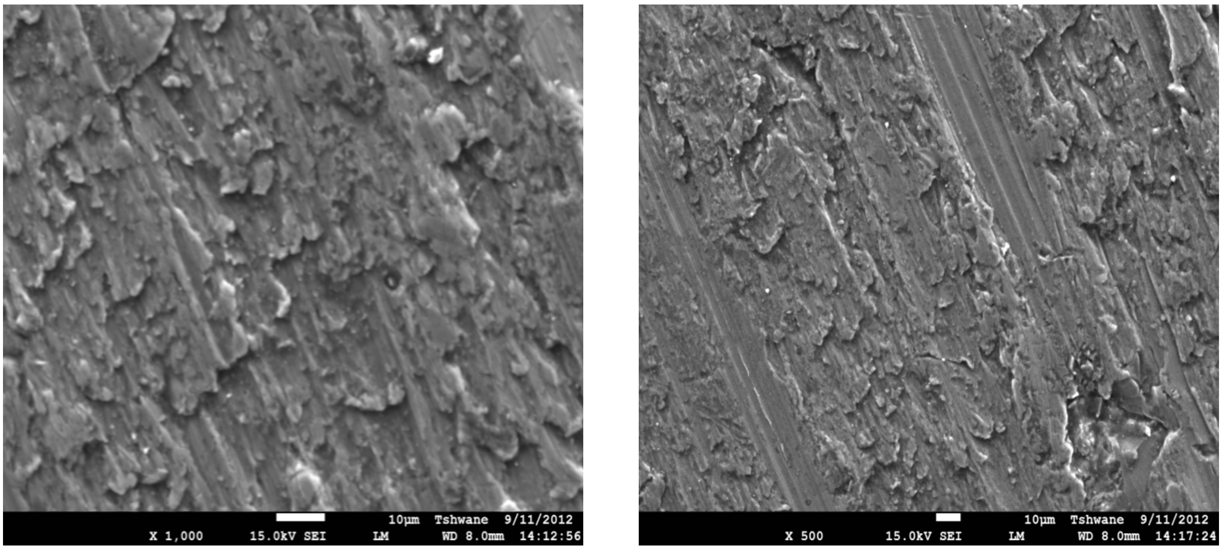

Fig. 4. SEM micrograph of inhibited Al-Si/SiC in 3.65% NaCl -0.5 g/v KI after 288 h of exposureat different magnifications.

3.2.4 Inhibitor efficiency and adsorption behaviour

The percentage inhibitor efficiency (% IE) of the Al-Si/SiC in NaCl solution was done using the equation reported [16]. The variation in the % IE using gravimetric (GM), potentiodynamic polarization-corrosion rate (PP-CR), potentiodynamic polarization-corrosion density (PP-I_{corr}), and linear polarization resistance (LPR) are presented in Figure 5. The results show that addition of KI increased the IE with an increase in the inhibitor concentrations. This is due to the fact that, as the KI addition increases, the surface area covered by this inhibitor increased hence higher IE was achieved. KI as an inhibitor can be said to exhibit a mixed-type corrosion inhibition because of the simultaneous change in the anodic and cathodic region during the electrochemical study. Equally, there exist correlations between GM and potentiodynamic polarization resistance. The adsorption mechanism has been demonstrated with a relationship between C/θ against C that indicated linearity at 298K in the environment (see Figure 6). Since the correction factors (R^2) were calculated and close to unity: GM (0.9049) and LPR (0.9979), a Langmuir adsorption isotherm is believed to have been obeyed.

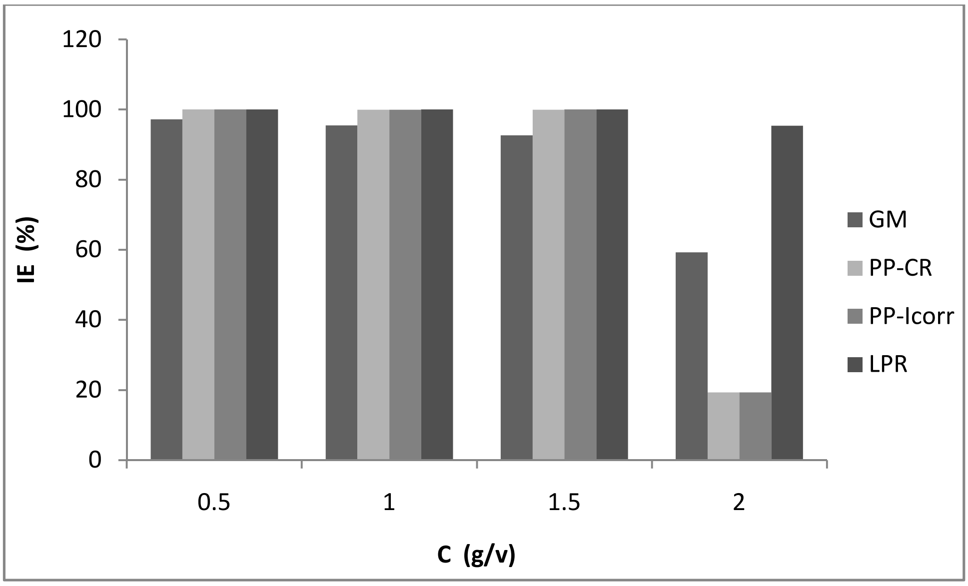

Fig. 5: Comparative chart of inhibitor efficiency (IE) for 3.65% NaCl solution/KI concentration obtained by gravimetric (GM), potentiodynamic polarization-corrosion rate (PP-CR), potentiodynamic polarization-corrosion current (PP-Icorr) and linear polarization resistance (LPR).

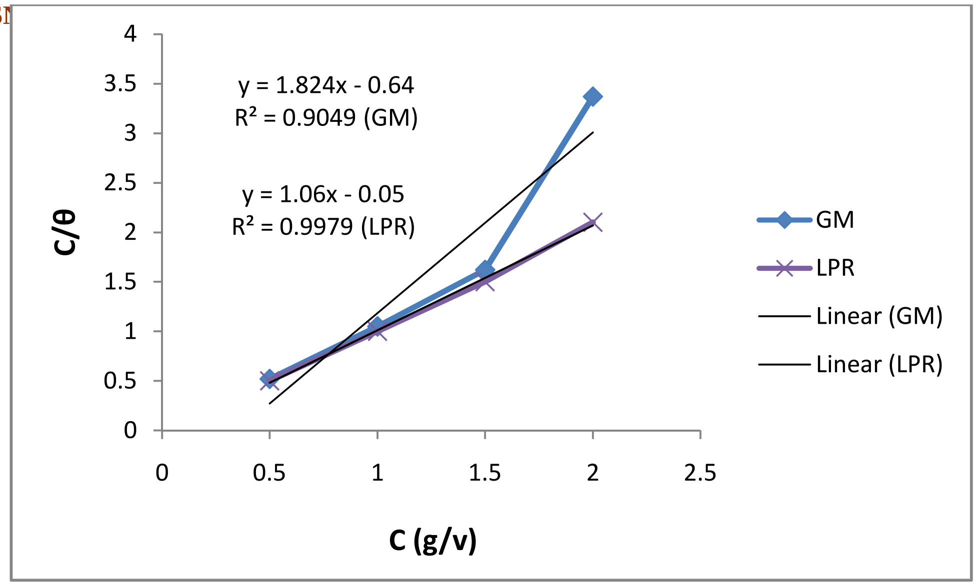

Fig. 6. Langmuir isotherm for the adsorption of KI compounds on the aluminium composite surface in 3.65% NaCl solution obtained by gravimetric and potentiodynamic polarization methods at 298K.

4. Conclusions

From the results and discussion above the following conclusions are made:

i. KI have been proved to be a good corrosion inhibitor in Al-Si/SiC in NaCl environment at $25^{o}C$

ii. The corrosion resistance and inhibitor efficiency of Al-Si/SiC composite increased with addition of KI as inhibitor with Inhibitor efficiency as high as 97.57% using the gravimetric method of corrosion evaluation.

iii. Surface morphology of uninhibited aluminium composite sample shows severe pits and cracks.

iv. A mixed-type corrosion inhibition exist and Langmuir adsorption isotherms were proposed for the aluminium composite in the environment considered.

Acknowledgements

The authors wish to acknowledge the Department of Chemical and Metallurgical Engineering, Tshwane University of Technology, Pretoria for providing the equipment used for the electrochemical corrosion test.

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