Inhibition Efficiency of 1-Butyl-3-methylimidazolium Bis(trifluoromethylsulfonyl)imide on AISI 316L in Strong Acid

Jan Vodenik[1], Marija Mitrović[2], Milorad Tomić[2], Regina Fuchs–Godec[1,*]

[1] *Faculty of Chemistry and Chemical Engineering, University of Maribor, Smetanova 17, Maribor*

[2] *Faculty of Technology Zvornik, University of Eastern Sarajevo, Karakaj bb, Republic of Srpska*

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[*]*regina.fuchs@um.si*

Abstract

The corrosion inhibition performance of the ionic liquid 1-butyl-3-methylimidazolium fluoromethanesulfonate (BMIFMS) on AISI 316L stainless steel was examined in the hydrochloric acid environments (1.0 M and 0.5 M HCl). The effects of BMIFMS concentration and immersion time on electrochemical behaviour were evaluated using potentiodynamic polarisation techniques over a 5-day period. Results show that BMIFMS does not significantly reduce corrosion current in 1.0 M HCl, except at the highest tested concentration (0.5 wt%), where a marked decrease in anodic current density and corrosion rate was observed. In contrast, in 0.5 M HCl, BMIFMS demonstrated a substantial inhibitory effect, with corrosion current densities reduced by up to three orders of magnitude and inhibition efficiency exceeding 99% at 0.5 wt%. The inhibition is attributed to the formation of a stable adsorbed BMIFMS layer, which is particularly effective in less aggressive corrosive media. The study highlights the influence of medium aggressiveness and ionic liquid concentration on the efficiency of corrosion inhibition.

Keywords: *stainless-steel; HCl; ionic liquid; adsorption*

Introduction

Ionic liquids are a distinctive class of salts that remain liquid at room temperature. They comprise organic cations (such as imidazolium, pyridinium, or ammonium) and various anions (for example, tetrafluoroborate, hexafluorophosphate, or sulfate), which together form stable liquids with low volatility, high thermal and chemical stability, and good ionic conductivity. Owing to these properties, they are often described as “green solvents”, as they can replace volatile organic solvents and thus reduce environmental impact. The applications of ionic liquids are varied: they are used as solvents in chemical synthesis, in electrochemistry (such as in batteries and supercapacitors), for separation processes, as catalysts, and as heat transfer media. A particularly interesting and rapidly developing area is their use as corrosion inhibitors. In this role, ionic liquids adsorb their cations and anions onto metal surfaces, forming a protective layer that prevents direct contact between the metal and aggressive agents such as acids, chlorides, or moisture. Their unique molecular structures enable strong interactions with metallic surfaces, resulting in highly effective corrosion protection even in harsh environments. One of the main advantages of ionic liquids as corrosion inhibitors is that they can be tailored by carefully selecting the cation and anion, allowing their efficiency, solubility, and environmental safety to be optimised for specific applications. In addition, their low volatility makes them significantly safer for humans and the environment compared to conventional inhibitors. For these reasons, ionic liquids are increasingly recognised as a promising solution for protecting metals in industrial systems, oil and gas infrastructures, and energy storage devices [1-3].

The aim of this study was to investigate the inhibition performance of the selected imidazolium-based ionic liquid, 1-butyl-3-methylimidazolium bis(trifluoromethylsulfonyl)imide (BMIFMS), as an environmentally friendly corrosion inhibitor for stainless steel AISI 316L in aqueous hydrochloric acid solutions at concentrations of 0.5 M and 1.0 M. Various concentrations of the ionic liquid were

tested: 0.1 wt%, 0.2 wt%, 0.3 wt%, and 0.5 wt%. Corrosion measurements were conducted using the classical electrochemical method. The inhibitory effect of BMIFMS was monitored after 1 hour of immersion and after 1, 2, 3, 4, and 5 days of exposure to the corrosive medium. Fourier-transform infrared spectroscopy (FTIR) was used to analyse the adsorption layers formed by BMIFMS on the stainless-steel surface.

Experimental

The conventional three-electrode configuration was used for the potentiodynamic studies. All potentials were measured against the saturated calomel electrode (SCE), and the counter electrode was platinum. Measurements were conducted within a potential range of ±300 mV relative to the open circuit potential (OCP), with a scan rate of 1 mV s^{-1}. Polarisation plots were obtained 60 minutes after the working electrode was immersed in the solution, allowing the stationary potential to stabilise. All experiments were performed at 25 °C ± 1 °C. Potentiodynamic curve measurements were taken after 1 hour of immersion and after 1, 2, 3, 4, and 5 days of testing. The measurements were performed using a Gamry 600™ potentiostat/galvanostat controlled by electrochemical software. Data were collected and analysed using CorrView and CorrWare software developed by Scribner Associates, Inc.

Results and discussions

Electrochemical results

The effect of BMIFMS on the current–potential characteristics displayed by the polarisation curves of stainless-steel type AISI 316L in 1.0 M and 0.5 M HCl after 1, 2, 3, 4, and 5 days of testing, is presented in the Figs. 1a-e and Figs. 2a-e. From the potentiodynamic curves shown in Figures 1a–e, it is clear that the addition of BMIFMS does not produce a significant inhibitory effect, as the corrosion current value does not decrease substantially. This is evident from the Tafel curves, which mostly overlap over time without a distinct downward shift that, according to the extrapolation method, would indicate a notable reduction in corrosion current and, consequently, effective inhibition (Fig 1a.). The only exception is at the highest concentration of 0.5 wt% BMIFMS in the corrosive medium (Fig 1b.). Similarly, no significant decrease in the cathodic current density is observed, whereas the area under the anodic peak (charge under the oxidation curves), shown in Figures 1c–e, is noticeably reduced. To determine the charge under the oxidation curves, we integrated from the corrosion potential, where the current is minimal, up to the selected potential of –0.1 V (vs.SCE).

Table 1. Inhibition efficiency at selected concentrations of the BMIFMS ionic liquid over a period of 1 hour to 5 days of sample immersion in 1.0 M HCl, determined from the charge under the oxidation curves

	0.2 % BMIFMS	**0.3 % BMIFMS**	**0.5 % BMIFMS**
***t* [h]**	**η_a [%]**		
1	48.92	42.11	60.28
24	50.90	55.38	86.76
48	55.92	65.98	86.81
72	60.00	62.89	86.95
96	61.27	66.75	85.81
120	67.89	67.01	84.50

$$\eta_a = \frac{A - A'}{A} \cdot 100\% \quad (1)$$

where:

η_a – inhibition efficiency of the anodic part

A – area under the curve of the unprotected sample surface

A' – area under the curve of the inhibited sample surface

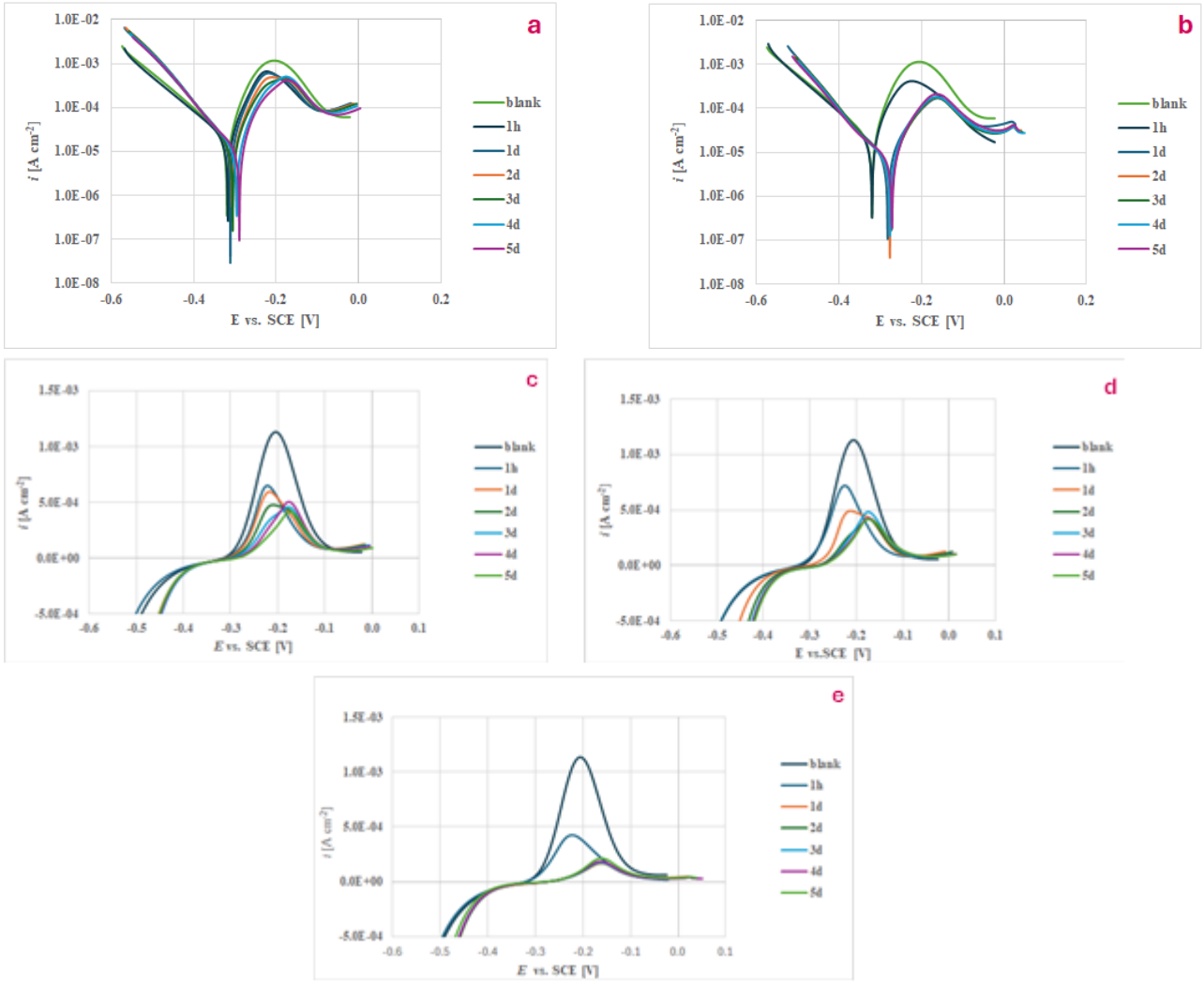

Figure 1. *Influence of the ionic liquid BMIFMS on the cathodic and anodic behaviour of AISI 316L in 1.0 M HCl at 25°C, after 1h, after 1, 2-, 3-, 4-, and 5-days duration test. a.) 0.2 wt% BMIFMS, b.) 0.5 wt% BMIFMS, c.) 0.2 wt% BMIFMS, d.) 0.3 wt% BMIFMS, e.) 0.5 wt% BMIFMS.*

Using Equation 1, the area of the inhibited region was compared with the area under the curve representing the response of the unprotected steel surface. In this way, the inhibition efficiency of the anodic part and its variations with time and BMIFMS concentration were determined, as summarised in Table.1. The difference in the reduction of the anodic current density/ charge under the oxidation curves shown in Figs. 1c and 1d is minimal or negligible. Therefore, this slight decrease in the anodic peak can be attributed primarily to the formation of a passive layer rather than to the adsorption of BMIFMS on the surface. In contrast, with the addition of 0.5 wt% BMIFMS, a pronounced decrease in the anodic peak and consequently in the anodic current density is clearly observed compared to the

responses in Figures 1c and 1d, which can be unequivocally attributed to the formation of an adsorbed BMIFMS layer. This is further confirmed by the increase in inhibition efficiency of the AISI 316L sample after 1 day of immersion, from 60% to more than 85%. While the use of 1.0 M HCl did not result in high inhibition efficiency of BMIFMS, except at the highest concentration added, significantly improved anticorrosion performance was observed in a solution that was twice as dilute (0.5 M HCl). This is confirmed by the reduction of the corrosion current density by up to three orders of magnitude. It can be concluded that the aggressiveness of the corrosive medium influences the adsorption efficiency of BMIFMS and, consequently, its inhibition performance. The high aggressiveness of the 1.0 M HCl medium likely causes the anodic reaction rate to dominate over the adsorption rate.

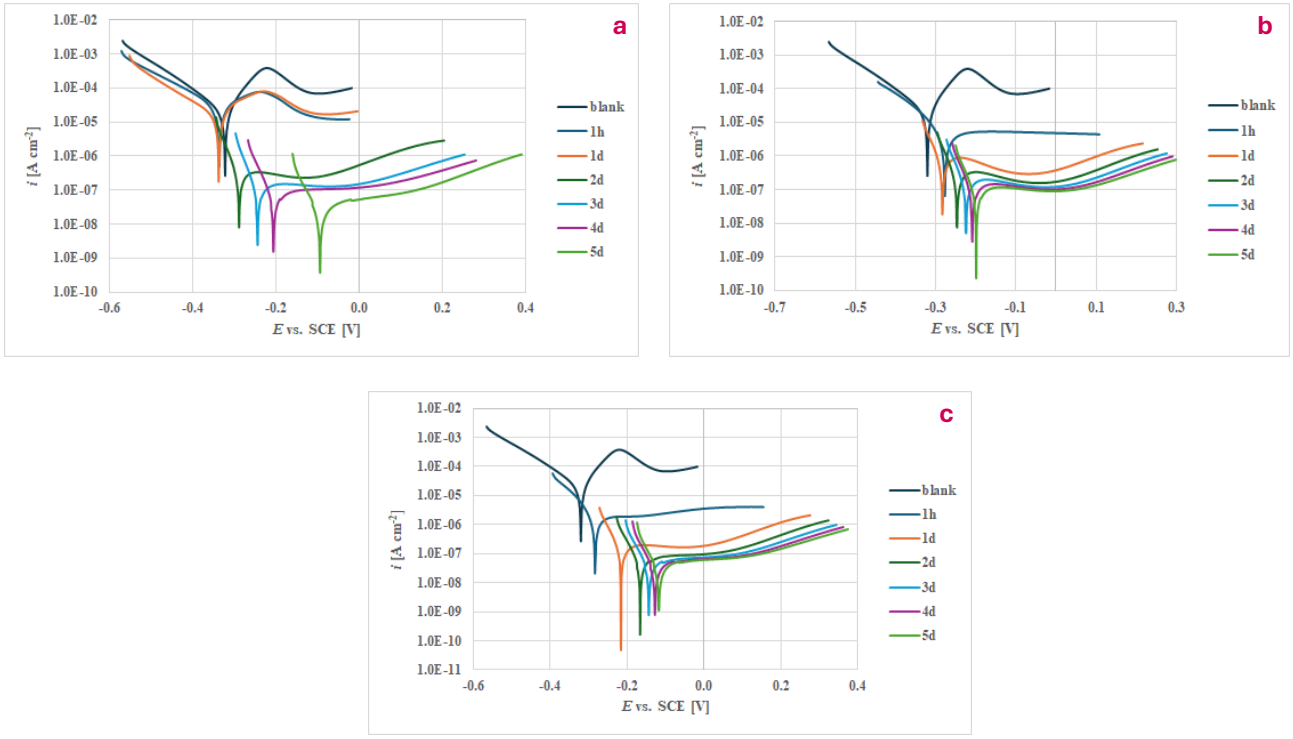

Figure 2. *Influence of the ionic liquid BMIFMS on the cathodic and anodic behaviour of AISI 316L in 0.5.0 M HCl at 25°C, after 1h, after 1, 2-, 3-, 4-, and 5-days duration test. a.) 0.2 wt% BMIFMS, b.) 0.3 wt% BMIFMS, c.) 0.5 wt% BMIFMS.*

Figures 2a–c illustrate the current–potential response as the concentration of added BMIFMS increases. At the lowest addition of 0.2 wt% BMIFMS, effective adsorption is observed only after 2 days of immersion. In contrast, for additions of 0.3 wt% and 0.5 wt% BMIFMS, a relatively high degree of adsorption is achieved after just 1 hour of immersion in the corrosive medium. The measurements further confirm that the adsorbed film remains stable even after 5 days of immersion in 0.5 M HCl, with inhibition efficiency exceeding 99.0%.

Table 2. Kinetic parameters for corrosion of SS AISI 316L for the bare surface after 1h, and for after 1, 2, 3, 4, and 5days duration test in the 0.5 M HCl at 25ºC at selected concentrations of the BMIFMS ionic liquid

time	β_C [V/dec]	β_A [V/dec]	i_{kor} [µA cm^{-2}]	R_p [kΩ cm^2]	E_{kor} [mV]	η_{ikor} [%]	η_{Rp} [%]
blank							
	0.133	0.077	26.96	0.746	-321.1	-	-
0.2 % BMIFMS							
1h	0.152	0.195	26.82	0.796	-335.9	0.50	6.28
1d	0.136	0.100	13.53	1.115	-337.0	49.81	33.12
2d	0.033	0.211	0.220	37.63	-288.7	99.18	98.02
3d	0.033	0.157	0.079	102.6	-242.4	99.71	99.27
4d	0.039	0.238	0.053	180.4	-206.3	99.80	99.59
5d	0.047	0.152	0.020	607.1	-92.53	99.93	99.88
0.3 % BMIFMS							
1h	0.063	0.179	2.418	5.565	-276.3	91.03	86.60
1d	0.040	0.190	0.560	17.53	-282.7	97.92	95.75
2d	0.037	0.176	0.196	47.32	-247.3	99.27	98.42
3d	0.037	0.167	0.111	80.79	-224.8	99.59	99.08
4d	0.037	0.153	0.077	114.4	-208.9	99.72	99.35
5d	0.036	0.143	0.059	140.3	-199.3	99.78	99.47
0.5 % BMIFMS							
1h	0.043	0.118	0.864	10.69	-284.8	96.79	93.02
1d	0.035	0.118	0.092	87.09	-217.4	99.66	99.14
2d	0.039	0.164	0.037	241.9	-165.1	99.86	99.69
3d	0.043	0.204	0.032	315.5	-144.2	99.88	99.76
4d	0.038	0.117	0.023	366.6	-128.4	99.91	99.80
5d	0.039	0.120	0.022	409.1	-117.7	99.92	99.82

Conclusion

The findings show that the corrosion inhibition efficiency of BMIFMS on AISI 316L stainless steel depends strongly on both the concentration of the ionic liquid and the aggressiveness of the corrosive medium. Minimal inhibition was observed in 1.0 M HCl, except at the highest concentration tested, whereas significant anticorrosive performance was achieved in 0.5 M HCl, even at lower BMIFMS concentrations. The improved performance in diluted acid is attributed to more favourable adsorption conditions, resulting in the formation of a stable protective film. Notably, the addition of 0.5 wt% BMIFMS provided over 99% inhibition efficiency after prolonged immersion. These results indicate that BMIFMS is a promising corrosion inhibitor for stainless steel, particularly in less aggressive acidic environments, where adsorption can effectively outcompete corrosion reactions.

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