



Influence of cathode and anode processes on tribocorrosion of aluminium alloy AA2024 in acid rain

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Abstract

The nature of cathodic processes during the frictional interaction of aluminum alloy with ball corundum in the conditions of reciprocating motion has been studied. Under conditions of anodic polarization under conditions of friction, corrosion processes are activated and their speed during friction increases many times. The potential on the surface of the alloy under acid rain shifts sharply in the negative direction. Changes in the tribopotential and coefficient of friction are characterized by a gradual shift in values at the initial stage of research. The oxide film is formed on the metal surface in neutral and acidic environments. The service life of the film is increased due to electrochemical protection during cathodic polarization at the electrode potential of pure alloy without oxide film. It is proved that polarization changes the life of the film in the initial stages and the loss of material and the coefficient of friction during the entire test period. It is established that the nature of surface fracture also changes as a result of application of the polarization potential during friction. The largest surface damage is observed during anodic polarization.

Keywords: polarization, corrosion, damage, secondary films, friction, cathode potential

Introduction

The destruction of materials in a result of tribocorrosion occurs in many industries: processing, energy, chemical and others [1]. Friction units operating in active media are the subjects of destruction. In such systems, wear can occur from the flow of liquids, collisions of particles or contact of solids. Therefore, the study of tribocorrosion processes and the influence of various factors on them is an urgent scientific and technical problem. Electrochemical methods are important to solve them [2 - 7].

There are two interrelated areas in the field of research of electrochemical processes at the friction of metals: the use of electrochemical parameters to obtain information about contact processes and an attempt to control friction and wear of materials using electrochemical methods [1]. The second direction - active intervention in the electrochemical processes on the friction contact - has received much less development than the first, although it seems quite promising. One of the control methods is the polarization of the friction system from an external source [8]. The method consists in the fact that the systems with the help of an external source of polarization is shifted to a certain area for the processes of friction and wear, and is maintained at a given level during the operation of the friction pair. Polarization of the friction system pursues various goals: to reduce surface energy, to improve the wettability and adsorption of environmental components, and others. Some cases of this method are anodic and cathodic protections, which change the corrosion-mechanical processes and the formation and destruction of secondary structures.

The purpose of the work – to study the frictional interaction of tribotechnical pairs: alloy AA2024 - corundum indenter, interacting in an acidic environment under conditions of cathodic and anodic polarization.

Materials and research methodology

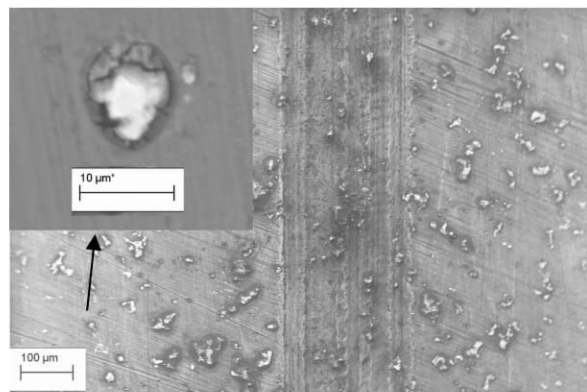
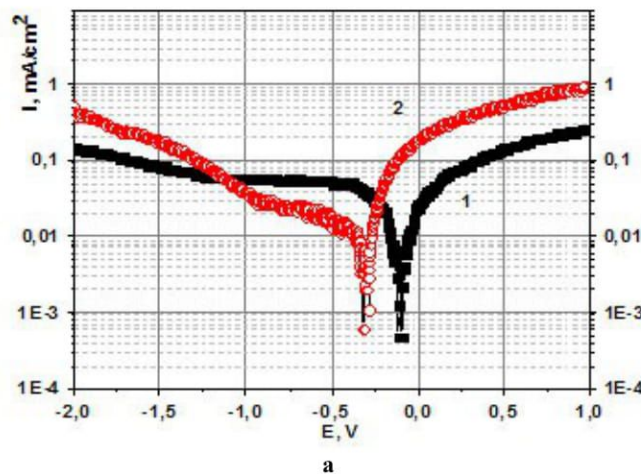


Tribocorrosion studies of aluminum alloy AA2024 (size of samples $50 \times 40 \times 5$ mm) were performed on a reversible friction test plant [5] according to the scheme "ball - plane". The load on the ceramic ball was 1 N, the length of the friction track - 24 mm, the speed of movement - 1.6 mm/s, friction time 20 min. During the tribocorrosion tests, the change in the friction moment was recorded and the polarization was set using the PI-50-1.1 potentiostat. A saturated silver chloride reference electrode and an auxiliary platinum electrode were used. The kinetics of changes in the measuring parameters were recorded by an analog-digital device by using a personal computer with a measurement step of 0.25 s. The working medium was acid rain [7] with a pH=4.5, reduced by the addition of Na_2CO_3 .

A scanning electron microscope EVO-40XVP (Carl Zeiss) with a system of micro-X-ray spectral analysis using an energy dispersion spectrometer INCA ENERGY 350 was used to study the surface of the aluminum alloy after corrosion mechanical wear.

Analysis of research results

It is established (Fig. 1, a) that the character of cathode processes changes during the frictional interaction of the AA2024 alloy with the corundum ball in the acid rain during the reciprocating motion of the indenter. There is an oscillation of corrosion currents in the polarization curve from the corrosion potential to -1.2 V (potential of freshly renewed surface) because there is a local change of cathode-anode processes on the deformed surface. It indicates the formation and destruction of secondary structures. At a potential below -1.2 V, hydrogen depolarization blocks the formation of films due to near-surface alkalinization of the interaction zone, which intensifies the rate of chemical corrosion. This is evidenced by the dissolution in the contact zone (Fig. 2, b), especially intense local corrosion at the sites of intermetallic compounds.



**Fig. 1. Polarization curves of AA2024 alloy (a) and its damage (b) during tribocorrosion at a potential of -1.6 V in acid rain:
1 – without load; 2 – during friction (P = 1 N, counter body: ball Al_2O_3)**

Under anodic polarization, both in stationary conditions and under frictional interaction, corrosion processes are activated, and their speed during friction increases 5 times.

Tribocorrosion studies have shown that potential on the surface of the alloy AA2024 in acid rain is $-0,520$ V without applying a load. Its potential shifts sharply to the negative side and becomes $-0,770$ V with the beginning of mechanical activation of the surface by a moving indenter. The average value of the friction coefficient gradually increases with the beginning of research and its value was established at the level of $\sim 0,43$ after a stage of running-in. Changes of the tribopotential and the coefficient of friction are characterized by a gradual shift of values at the initial stage of research. The oxide film is formed on the metal surface in neutral and acidic environments [4]. This film contacts with the indenter, destructs and is removed from friction zones during the friction.

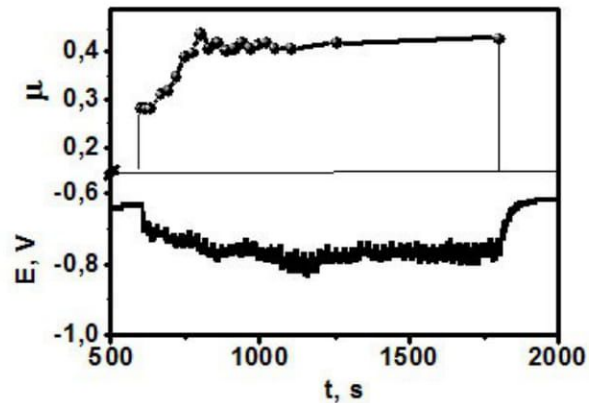
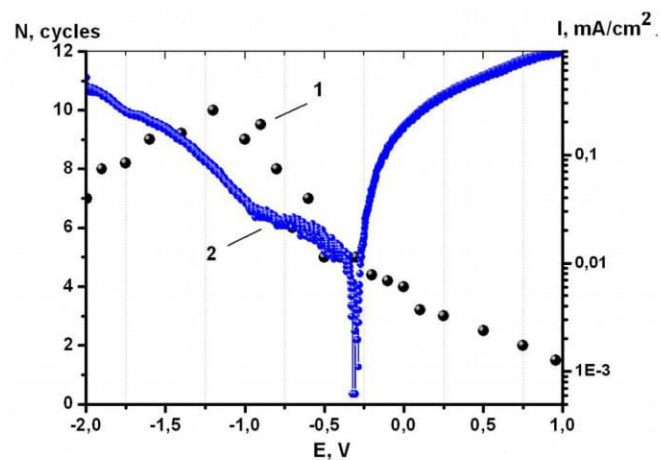


Fig. 2. Time dependences of friction coefficient and corrosion potential of aluminum alloy AA2024 during tribocorrosion studies in acid rain solution

It was found (Fig. 3 a) that, this film is destroyed in 6 passes of the indenter without the potential applying. The change of the polarization potential from stationary potential in the cathode and anode sides significantly changes the lifetime of the film. The lifetime of the film increases due to electrochemical protection at cathodic polarization in the range of $-0.700\dots-1.200$ V. It is most evident at the electrode potential of pure alloy AA2024 without oxide film (-1.200 V). The destruction of the film intensifies as the potential increases in the negative direction from the potential -1.200 V. The reason for this is the near surface alkalization of the environment due to the increase in the rate of hydrogen depolarization [10]. When level of polarization increases, the chemical corrosion intensifies, and the destruction increases. Friction during anodic polarization significantly accelerates processes of electrochemical corrosion and intensifies the destruction of the film. Damage of film occurs without the frictional interaction at potentials of $0.750\dots 1.000$ V and the indenter already removes its remnants from the contact zone. Polarization changes the lifetime of the film in the initial stages of tribocorrosion tests. Also it changes the material loss and friction coefficient for the entire period of tribocorrosion tests (Fig. 3 b, c). Cathodic polarization reduces material loss. So the width of the track on the surface without polarization is 230 μm and it is reduced to 225 μm with a potential shift in the negative direction.



a

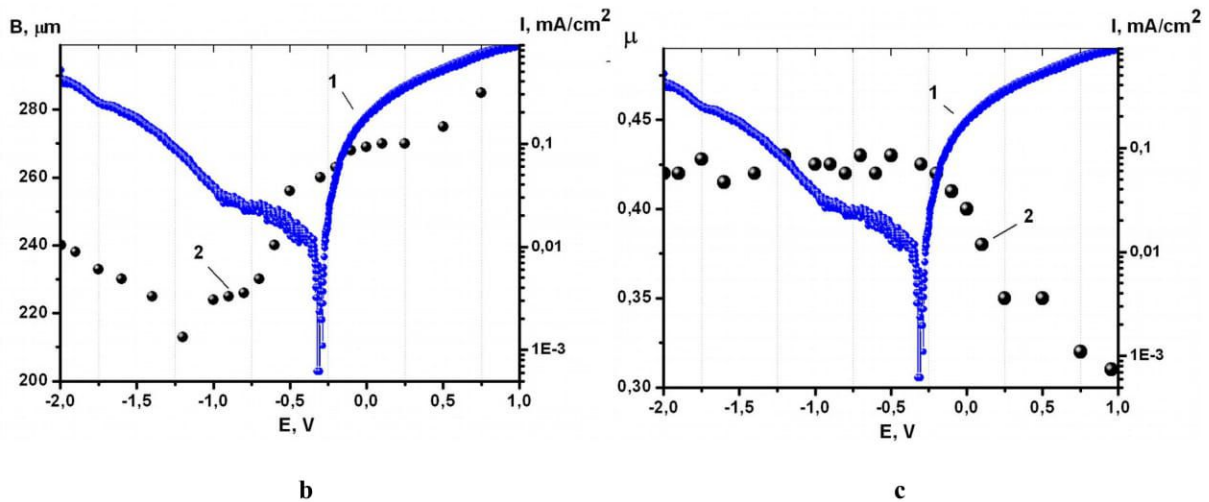


Fig. 3. Dependence of the rate of destruction of the oxide film (a), material loss (b) and friction coefficient (c) on the polarization potential of the alloy AA2024 by friction in acid rain in contact with a ceramic ball (1N):

1 – polarization curve of AA2024 alloy for tribocorrosion;

2 – parameters:

a – destruction of the film;

b – the width of the friction track; c - coefficient of friction

The smallest material losses are observed at a potential of -1.200 V, due to the maximum inhibition of corrosion processes, the track width is 212 μm . Shifting the potential to more negative values, as in the case of natural oxide film (Fig. 3 a), leads to alkalization of the environment and intensification of corrosion processes. Material losses increased due to corrosion-mechanical wear. Anode polarization, which is only 0.100 V relative to the steady-state potential, increases the width of the wear track by 20 μm . With a shift of the polarization potential to a more positive side, the loss increases the material loss and at a polarization potential of +1,000 V is 45 % compared to an alloy without polarization.

It is established that the dependence of the friction coefficient on the polarization potential for tribocorrosion has the opposite character to the material loss. It is to some extent abnormal for most tribological processes. Cathodic polarization does not change the value of the coefficient of friction, the increase occurs only at the potentials -0.120 V (maximal inhibition of corrosion processes). Anodic polarization intensifies corrosion processes, accelerates the formation of secondary structures, which consist mainly of Al (63.2 mass. %) and O (32.19 mass. %) (Fig. 4). It reduces adhesion interaction of friction surfaces. So, with increasing polarization potential, the coefficient of friction decreases from 0.43 to 0.32 at a potential of 1.000 V.

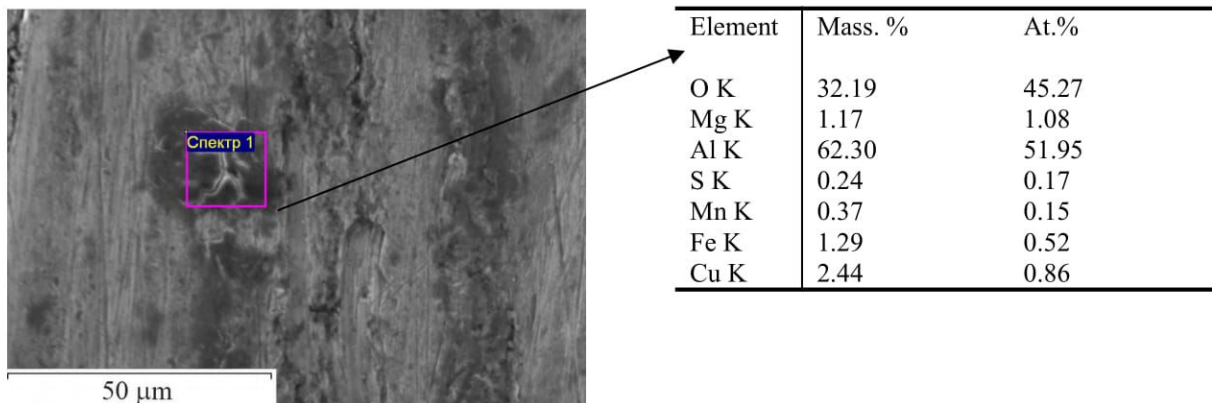


Fig. 4. Chemical composition of secondary structures, which are formed by anodic polarization (0.100 V) of AA2024 alloy during tribocorrosion

The nature of the surface destruction also changes in a result of the application of the polarization potential during friction (Fig. 1b and Fig. 5). Thus, the greatest surface damage is observed during anodic polarization. For example, there are etches and products of the combined action of corrosion and friction - especially active local corrosion - at a potential of 0.500 V on the surface (Fig. 5a). The appearance of microcutting elements is found on the material without the application of polarization (Fig. 5, b). Under these conditions the rate of secondary structures formation decreases compared to anodic polarization and the adhesive interaction between the contact surfaces increases. The surface damage decreases in the case of the polarization

potentials shift in the cathode direction, as electrochemical corrosion is inhibited, but the role of chemical dissolution increases. There is a change in the mechanism of corrosion, and therefore the mechanism of friction at the potential of the freshly renewed surface (-1.200V). At this potential, electrochemical corrosion is practically blocked, but chemical corrosion begins to intensify due to near-surface alkalization of the environment.

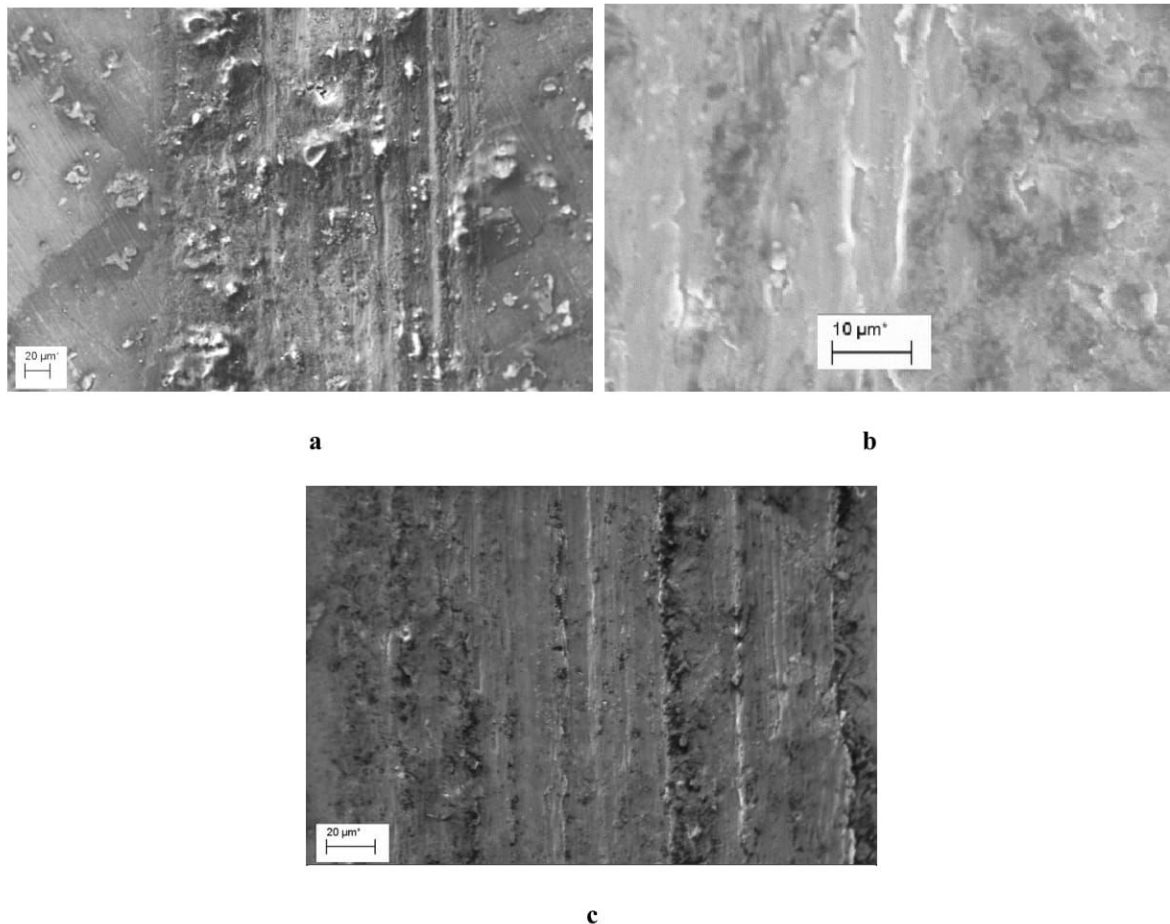


Fig. 5. Topography of the surface of AA2024 alloy after tribocorrosion studies in acid rain at different potentials of polarization:
a – polarization at +0.500 V;
b – without polarization;
c -- polarization at -1.200 V

As the rate of hydrogen depolarization increases, the concentration of hydrogen in the near-surface layer increases and the pH of the solution changes intensively. It is manifested in the local etching of intermetallic inclusions in the contact zone (Fig. 1b).

Thus, depending on the level of cathodic and anodic polarization, the intensity of destruction of the AA2024 alloy during tribocorrosion in pair with corundum counter body changes.

Conclusions

1. The influence of external cathodic and anodic polarization on tribocorrosion of AA2024 alloy paired with a ceramic ball in acid rain has been studied.
2. The dual influence of cathodic polarization on the tribocorrosion of AA2024 alloy is established. The destruction of metal is inhibited at the potentials below the potentials of the freshly renewed surface. It is due to the reduction of the corrosion rate. Above this potential, corrosion-mechanical wear intensifies due to alkalization of the near-electrode layer of the electrolyte in a result of hydrogen depolarization. Changes in the coefficient of friction are insignificant.
3. It is shown that the anodic polarization intensifies the formation of secondary structures. As a result, there is an increase in losses of materials and the decrease of friction coefficient. It indicates the lubrication properties of products that are intensively removed from the friction zone.

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Хома М., Винар В., Х. Василів, Ковальчик Ю. Вплив катодних і анодних процесів на трибокорозію алюмінієвого сплаву AA2024 у кислотному дощі.

Досліджено характер катодних процесів під час фрикційної взаємодії алюмінієвого сплаву із кульковим корундом в умовах зворотно-поступального руху. В умовах анодної поляризації в умовах тертя активізуються процеси корозії і їх швидкість під час тертя збільшується в рази. Потенціал на поверхні сплаву під кислотними дощами різко зміщується в негативну сторону. Зміни трибопотенціалу та коефіцієнта тертя характеризуються поступовим зміщенням значень на початковому етапі досліджень. Оксидна плівка утворюється на поверхні металу в нейтральних та кислих середовищах. Термін служби плівки збільшується за рахунок електрохімічного захисту при катодній поляризації при електродному потенціалі чистого сплаву без оксидної плівки. Доведено, що поляризація змінює час життя плівки на початкових етапах та втрати матеріалу та коефіцієнт тертя протягом усього періоду випробувань. Встановлено, що характер поверхневого руйнування також змінюється в результаті застосування потенціалу поляризації під час тертя. Найбільші поверхневі пошкодження спостерігаються під час анодної поляризації.

Ключові слова: поляризація, корозія, пошкодження, вторинні плівки, тертя, катодний потенціал