EXPERIMENTAL INVESTIGATIONS OF ALUMINIUM ALLOYS 2024 –T 3 FORM IN TERMS OF TRIBOCORROSION CHARACTERISTICS

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Abstract

Results of” ball on disc” principle tests to examine the friction coefficient and wear rate of Aluminium Alloys 2024–T3 are presented. Tribocorrosion experiments were performed using a pin on disc tribometer under controlled electrochemical conditions in NaCl solution. This paper reviews the available knowledge relating to the tribocorrosion. Tribocorrosion can be defined as a degradation phenomenon of material surfaces (wear, cracking, corrosion, etc.) subjected to the combined action of mechanical loading (friction, abrasion, erosion, etc.) and corrosion attack caused by the environment (chemical and/or electrochemical interaction), as highlighted in Figure. Experimental confirmations of improving electrochemical properties of the aluminium alloy AW 2024 by anode oxidation and extension of the period of excitement AW 2024 after adjusting surface anode oxidation are documented.

Keywords: tribology, corrosion, tribocorrosion, research, coatings, layers

1 Introduction

The need to select or design new surfaces for future equipment as well as minimize the operating costs and extend the life of existing machinery has led to demands for a much better understanding of surface degradation processes particularly when tribological components are operating in corrosive environments. This has given rise to the active research area of tribocorrosion which seeks to address the concerns above and understand the surface degradation mechanisms when mechanical wear and chemical or electrochemical processes interact with each other.

Corrosion is the physicochemical interaction between metal and environment. Corrosion resulted in permanent chemical changes of metal and therefore metal changes his chemical, physical and mechanical properties [1, 2]. Corrosion of the most technical metals is spontaneously because of metals tendency to achieve the thermodynamically stable state. Most of the technical metals (except copper, silver, gold and platinum) are no-noble and therefore it is presumption of interaction with environment in common conditions. It is very important to know the corrosion rate of the metal in specific media. The corrosion rate is the rate of the changing the metal to its corrosion product and it is determining by the rate of chemical reactions or by the rate of the transport of active components near metal surface. If the corrosion products are

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simply or complex ions and they are soluble in corrosion media then the metal is in active state. Some metals in some specific media during interaction between metal and environment create the insoluble corrosion products with low porosity and with good adhesion to metal surface. The metals with natural passivation ability are stable in common media [3].

Existence and/or rebuilding rate of the passivation layer after its damage determine the corrosion resistant of the metal surface during tribocorrosion processes. Rebuilding of the layer is described by electrochemical conditions in the corrosion system. The full range current density – potential corrosion diagram describes the metal-environment processes. The typical corrosion diagram for the metal with ability for passivation in media is in **Fig. 1**.

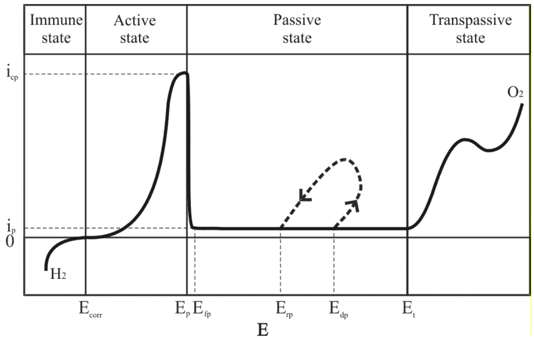

Fig.1 Full range corrosion diagram [4, 5]

At the potentials lower than Ecorr the cathodic partially reaction accelerates and anodic partially reaction decelerates. Metal is in immune state. The part of the polarization curve at potentials over Ecorr corresponds to active state of the metal surface (metal is dissolving). The conditions for creation of insoluble corrosion products (with good adhesion to metal surface) arise at the maximum of the current density (icp, Ep) at the interface of active and passive state. The surface is full passivized at the full passivation potential and corrosion density decreases to very low, technical acceptable value [1, 4].

Transition of the metal surface to the passive state depends on ability to overcome of critical passivation current density icp. Creation of the passive layer is easier with lower value of the icp. On the other hand, metal can be passivized in operation media with high oxidative capacity for this metal. E.g. common steel corrodes in the distilled water or in the diluted nitric acid but same steel can be passivized in concentrated nitric acid. Some metals like Al, Ti, Zr, Cr or stainless steels (with Cr content above 12 wt.%) have critical current density value lower than oxidative capacity of common atmosphere or common water [4, 5].

Tribocorrosion has evolved into a new and emerging area of research with many applications going beyond the conventional. It is basically an integration of two major areas of significance and application in mechanical systems namely Tribology and Corrosion [6, 7]. Tribology is the science of friction, wear, and lubrication, whereas corrosion relates to chemical aspects of the material degradation in mechanical systems [8, 14, 15, 16, 19].

Tribocorrosion can be defined as a degradation phenomenon of material surfaces (wear, cracking, corrosion, etc.) subjected to the combined action of mechanical loading (friction, abrasion, erosion, etc.) and corrosion attack caused by the environment (chemical and/or electrochemical interaction) [10, 17, 18, 20], as highlighted in **Fig. 2**

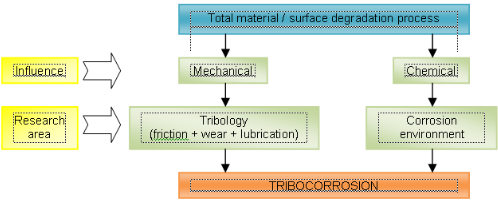

Fig.2 Basic concept and definition of tribocorrosion

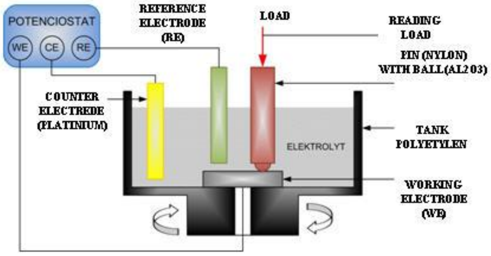

Fig.3 A schematic set-up of the electrochemical cell

2 Methodology tribological properties measurements

Tribological studies deal with mechanical parametres describing the interaction between contacting surfaces. As mentioned earlier, in order to study the tribocorrosion behaviour, mechanical and corrosion responses from the tribocorrosion test system are required to be collected and monitored. Generally, tribometer has facility to measure the evolution of frictional forces and electrochemical technique is used to monitor the corrosion response from the test system. A schematic diagram of the basic methodology of a tribocorrosion test system is shown in **Fig. 3**. The basic test system used in tribocorrosion test is the pin-on-disk system. Electrochemical interfacing consists of a potentiostat and three electrode attachments, such as reference electrode (RE) and counter electrode (CE). The sample is acting as the working electrode (WE) [13].

3 Factors affecting tribocorrosion process

Tribocorrosion behavior depends on the properties of the contacting materials, the mechanics of the tribological contact, and the physicochemical properties of the environment. These aspects are strongly interrelated-either synergistic or antagonistic, which can have beneficial or deleterious influence over the performance of the tribological system.

Wherever the film is mechanically damaged and removed, the charge transfer can take place at the interface without any resistance from the barrier film. This interaction between tribological and electrochemical corrosive effects increases loss of materials significantly. It will be much higher than the summation of material loss under pure corrosion (without tribological movements) and pure wear conditions (preventing corrosion under cathodic conditions) [11, 12].

4 Material Alloy 2024-T3

EN AW 2024–T3 aluminium alloy was used as an experimental material. Chemical composition of EN AW 2024–T3 is specified in **Table 1** [2].

Table 1 Chemical composition of EN AW 2024–T3 aluminium alloy [2]

Element	**Si**	**Fe**	**Cu**	**Mn**	**Mg**	**Cr**	**Zn**	**Ti**	**Al**
% volume	0.5	0.5	3.8-4.9	0.3-0.9	1.2-1.8	0.1	0.25	0.15	rest

The samples had circular shape with dimensions ϕ 40x3 mm and were polished on the mirror surface. All samples were cleaned with ethanol, dried and electrochemically treated by anodic oxidation in solution before testing.

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5 Anodic oxidation

Anodic oxidation is one of the most used methods of aluminium corrosion protection. So-called "hard" anodic oxidation method was used for creating of eloxed layer on the surface of all tested samples. The anodic oxidation process had been realized under constant electric current density of 40 mA·cm^{2} in 250 gdm^{-3} H_2SO_4 under the temperature of 0 ± 0.5 °C during 15 minutes and during 30 minutes.

After finishing of the anodic oxidation process the samples were splashed with cold water, dried and sealed into the demineralized hot water with temperature of 97 °C. Created anodic layer is built by unporous layer (insulating layer) with the fine porous layer on the surface (so-called cover layer). The fine porous layer had been created from unporous layer (insulating layer) by its reverse melting in the electrolyte. Insulating layer is renewed during chemical transformation of aluminium to aluminium oxide with equal speed to the speed the cover layer was created [16]. Common oxidic layer with thickness of 0.05 μm grown to layer with 15.7 μm thickness during 15 minutes of anodic oxidation. Thickness of this layer increased to 30,1 μm after 30 minutes of anodic oxidation. The layer created after anodic oxidation is nonconductive, very hard and welded to aluminium material. Metallographical records of newly created oxide layers after 15 minutes and 30 minutes lasting hard anodic oxidation are shown in **Fig. 4** and **5**.

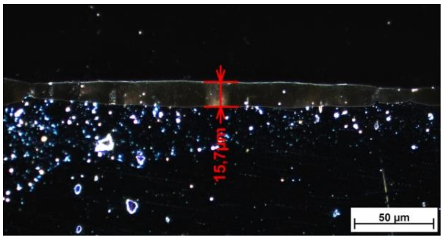


Fig.4 Metalography of oxidic layer after 15 minutes of hard anodic oxidation

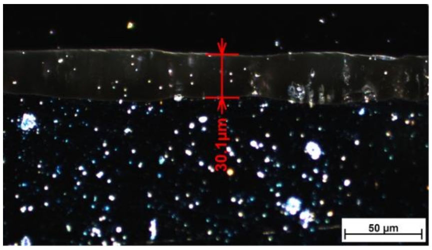


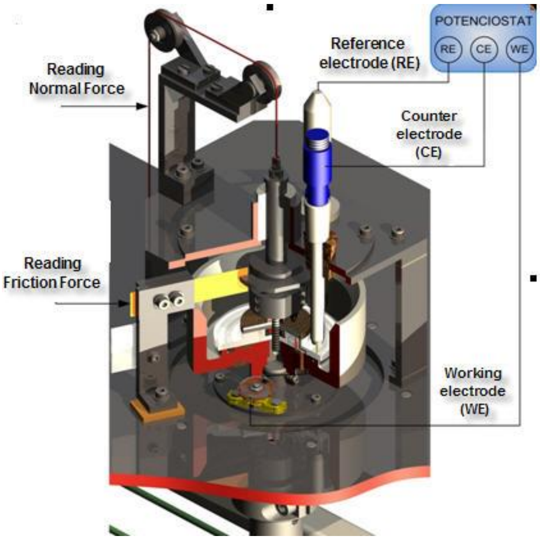
Fig.5 Metalography of oxidic layer after 30 minutes of hard anodic oxidation

Microhardness of experimental material was evaluated on Innovatest 400 series hardness tester. Microhardness of basic material evaluated by HV 0.01/10 method was 115 HV and microhardness of oxide layer section after hard anodic oxidation was 325 HV. It is clearly visible that the oxidic layer created within hard anodic oxidation is almost 3 times harder than hardness of noneloxed basic material.

6 Tribocorrosion test

The experimental tester “Rotatory micro- tribometer” was used for experimental testing of the tribocorrosive characteristics of material with anodic layer. This device allows microscopical examination of friction and wear processes. It is a machine with point contact between friction elements.

The behaviour of friction and electrochemical coefficients in dependence on the time had been evaluated. The corundum point with the round radius R = 0.08 mm and cone angle 45° was used for all measurements (**Fig. 7**). There is a normal force F_N acting in the direction of the z-axis which might be regulated by the change of the weight of the loading head. A pin on the end is connected with loading head. The friction force in described construction arrangement is generated by the friction pair created by ball and tested samples on disc. The value of the friction force F_T or friction moment M_T is determined by strain gage measurements applied on flat spring deformation.



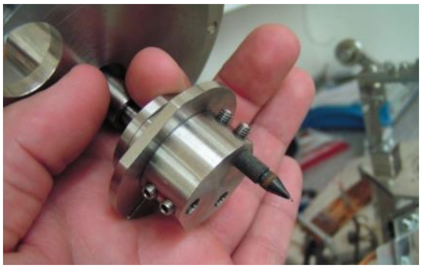


Fig.6 A schematic set-up of the electrochemical cell

Fig.7 View of the head and the tip (Al_2O_3)

The values of the friction coefficient are calculated from the known forces F_T and F_N. The time of the experiment was set to 80 minutes, the applied load was F_N = 1.5 N, and constant sliding speed $v = 0.015\ m \cdot s^{-1}$. The diameter of tribological track was 20 mm, sliding trajectory length of each sample was set to 100 meters. The measurements have been realized in NaCl solution under the surroundings´ temperature of 20 °C.

Time for stabilization of measurement conditions was 600 sec in all experiments. The surfaces friction leads to erosion of oxide layer and to the subsequent change of electrochemical potential towards negative values as can be seen in **Fig. 8, 9** and **10**.

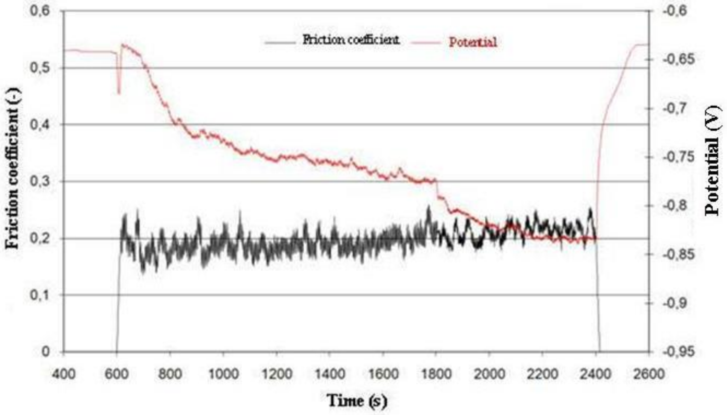


Fig.8 Friction coefficient and potential during sliding as function of the sliding time between AW 2024L and Al_2O_3 (tip)

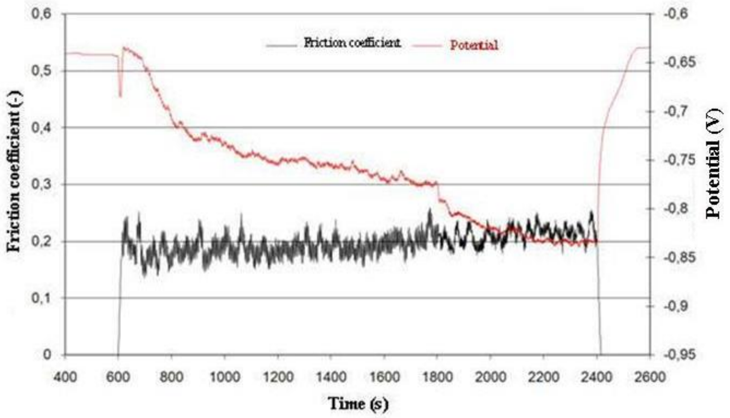


Fig.9 Friction coefficient and potential during sliding as function of the sliding time between AW 2024-15 (15 min) and Al_2O_3 (tip)

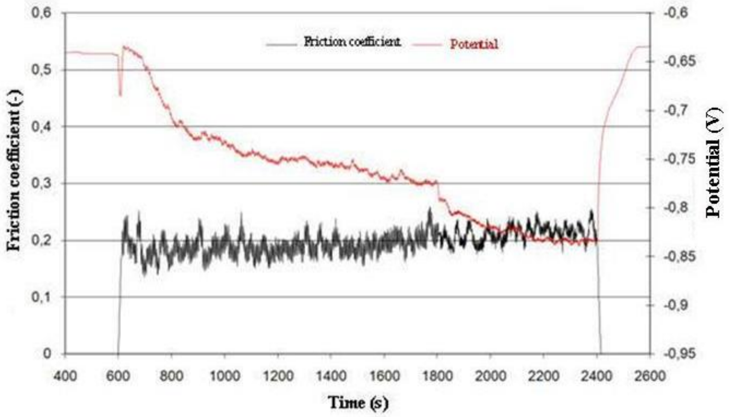


Fig.10 Friction coefficient and potential during sliding as function of the sliding time between AW 2024-30 (30 min) and Al_2O_3 (tip)

The time in which the electrochemical potential of -0.8 V, -0.895 V, -0.9 V, and -0.95 V had been reached was read in order to compare the obtained results of experimental samples with created anodic layers. The obtained data are displayed in the **Table 2**.

Table 2 Readout values

Corrosion potential	**-0.8 V**	**-0.85 V**	**-0.9 V**	**-0.95 V**
AW 2024 AON 15 min.	375 s	462 s	605 s	1338 s
AW 2024 AON 30 min.	1117 s	1300 s	1576 s	2281 s

From the comparison of the obtained results we can conclude that the time for renovation of electrochemical potentional to the same level for the samples which are in the anodic oxidation process for 30 minutes was 3 time longer when compared to samples being in the anodic oxidation process for 15 minutes.

7 Evaluation of surface topography

For better understanding of tribological processes – specifically wear – it is appropriate to undertake an evaluation of a topology samples. Wear rate evaluation through the use of friction track width was done by stereomicroscope Nikon AZ100 and AFM microscope SOLVER NEXT. **Fig. 11** shows tribological track created during the test on the surface of the sample. The wear track is nearly 500 μm wide. There is also no coating abrasion created during the tests. For illustration the **Fig. 12** shows 3D image of worn surface for AW 2024 in tribosystem with NaCl solution after tests were completed.

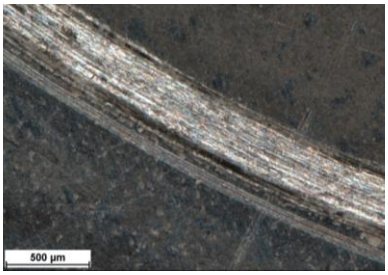


Fig.11 2D – Image of tribological track on the surface of the sample

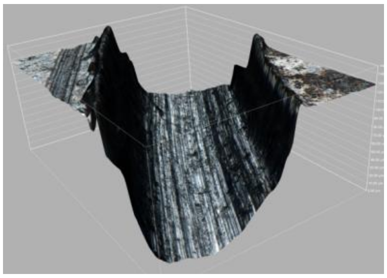


Fig. 12 3D – image of worn surface for AW 2024 tribosystem in NaCl solution

8 Conclusions

A wide range of corrosion resistant materials rely on a relatively thin surface oxide film to provide a barrier to charge transfer between the relatively active bulk material and the corrosive environment. This film renders the surface passive, but within the tribological contacts, the passive film can be removed by mechanical wear. The following conclusion can be drawn:

- Adding the Al_2O_3 reinforcing particles into the matrix causes improvement of the corrosion resistance of the investigated materials.
- Improving electrochemical properties of the aluminium alloy AW 2024 by anode oxidation.
- Extension of the period of excitement coating aluminium alloy AW 2024 after adjusting surface anode oxidation.

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