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New means for calculating sliding pairs corrosive and mechanical wear

Key words

Corrosive and mechanical wear, new method of calculation.

Słowa kluczowe

Zużycie korozyjno-mechaniczne, nowa metoda obliczeniowa.

Summary

This paper presents the author's calculation model for metals abrasive wear in electrolytic environments. The model occurred in the effect of elements synthesis of procedures proposed by various research workers as well as the algorithm elaborated by the author of this paper. The own elaborated algorithm enables the complete simulation of the corrosive and mechanical wear course of rough surfaces in pin – on – disc pairs. The new attitude lies, among others, in the simulation of the transformation process of "the technological roughness in the service one". The paper includes also the comparison between the calculations results and the experiments results. For simulation model verification the tests results of the team S. Mischler, D. Landolt and P. Jemmely [11] were used.

1. Introduction

Actions aiming at the elaboration of methods enabling "creating" reliability parameters of friction pairs in the phase of designing machines have been performed for many years at the Technical University in Poznan. Such pairs in majority of mechanical systems determine their durability. The elaborated ap-

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proach combines knowledge on mechanisms of wear processes with abilities of computer simulation technologies. A certain stage of development of these works had been presented in the monograph [1], however next steps gave the possibility to evaluate profile changes of machine elements in the effect of wear (the method of finite differences characterized in the paper [2] was applied).

Further works concerned the influence of active environments, on the metal wear process, classified in the following three groups:

- chemically inactive – surface active substances; their influence on mechanical properties manifests mainly through adsorption and chemisorption (the Rebinder effect),
- corrosion active – water, electrolytes, saline solutions; the effect of such substances is of chemical or electrochemical character,
- absorbed to the metal volume (its surface layer) – e.g. hydrogen or other elements creating solid solutions with metal.

Synthesis of views on probable mechanisms of these phenomena is presented among others in the monograph [1] which author took inspiration from G.V. Karpenki's works [3] bringing essential advancement to the interpretation of influence of environments containing surface acting substances and corrosion active components on metals. G.V. Karpienko formulated an adsorption and electrochemical hypothesis the essence of which is the opinion that adsorption of surface active substances is primary in relation to anode pulping of metal structural fragments. Adsorption causes inevitable, from the point of view of thermodynamics, lowering of surface energy level what makes gaps creation easier. Then there starts the corrosion process increasing gaps. Gaps creating operation of corrosive products and tensile stresses causing passive layers destruction promote that.

The above mentioned effects occur in working elements (pairs) of technological systems in food, chemical and petroleum industries [4,5]. This paper presents in details the wear problems of friction pairs working in electrolytes, so they are subjected to corrosion and mechanical interactions. It is an attempt to formulate an algorithm allowing to evaluate the intensity of wear in complex input conditions. Thus, there was started the search for calculation procedures:

- enabling simultaneous evaluation of material losses caused by two elementary destructive mechanisms,
- reflecting general process course tendencies (the influence of forcing factors changes to the material loss speed),
- enabling calculations only on the basis of certain basic data characterizing design and service conditions.

Literature review [6–11] concerning the mathematical modelling of corrosive and mechanical wear indicates that none of the presented ideas meets all assumptions of the complex computable algorithm (table 1). It arises mainly due to the lack of complete process presentation. Majority of elaborations concentrates only on corrosive interactions in friction conditions. Models where any phenomena causing the material loss were missed or significantly simplified cannot be treated as reliable analytic research instruments. The key matter for the correct description of wear in complex input conditions is determining the interactions between elementary destructive processes. Only G.E. Łazarew [10] suggested analytic methods for determining both elements of corrosive and mechanical wear; and its complex character. Although, it can be applied in the limited range. Making calculations with the use of it, however, requires the knowledge of specific data (current intensity and roughness in the friction area) characterizing the wear process and exceeding the range of information being known by a designer. In the light of the mentioned limitations concerning the known contemporary models of the corrosive and mechanical wear the author of this paper tried to formulate his own computable algorithm.

2. Formulating autor's computable algorithm

Analysis of hitherto elaborated analytic models shows clearly that the perception way concerning elementary destructive mechanisms determines the computable possibilities of the final mathematical formula. Only formulas basing on the coherent theory explaining the nature of occurring phenomena can be used to forecast the wear course. The author of the paper assumed the following corrosive and mechanical wear interpretive model. While the pair elements are at rest their surface can be covered with a layer of passive oxides. When they start the movement in the effect of relative displacements the corrosion products are removed and the clean metal surface is physically exposed. Then, in the region of the real contact the surface deformation takes place leading to the loss of the material base fragment. On the newly exposed surface the electrochemical processes start (at first anode digestion and then again the passivation). Next, material base oxidation leading to the creation of the new layer of passive oxides.

The frame of this paper author's computable algorithm is the model proposed by G.E. Łazarewa [10]. Modules of getting data respective to real service conditions are introduced as an addendum. First of all there are elaborated the following:

- a model of generating the course of corrosive current – its base is a model of passive layers increase described in the work [9],
- a modulus simulating changes of surface roughness – precise location of interactions (showing actual microroughness) should enable forecasting changes of surface microgeometry in relation with a general model of corrosive and mechanical wear (this paper author's own proposal).

Creation of computable algorithm lied in connecting the above mentioned procedures to obtain a coherent structure. The idea of algorithm was based on three assumptions:

– mechanical and corrosive interaction are of cyclic character – each interaction is analysed by a separate block of computable procedures in a sequence being in accordance with the assumed interpretive model,
– all elementary interactions change the condition of the material surface influencing the further wear process course – "inheriting" the effects of the previous step of interactions is used in the algorithm for taking into account the interactions between friction and corrosion,

material losses caused by elementary destructive processes are determined on the basis of data relevant to real service conditions – in the computable block of every interaction you can find an analytic data gaining modulus.

Table 1. Entire characteristics of corrosive and mechanical wear models
Tabela 1. Zbiorcza charakterystyka modeli zużywania korozyjno-mechanicznego

MODELS	INCLUDED INPUTS		MECHANICAL WEAR				CORROSIVE WEAR			
	pair loading	electrochem. potential	process model		presentation of specific reactions(1)		process model		presentation of specific reactions(1)	
			interpretative	computable	calculations	measurement	interpretative	computable	calculations	measurement
T.A. Adler i R.P. Walters [6]	■			■		■		■		■
H. Abd-El-Kader [7]		■					■	■		■
S. Mischler [8]	■	■						■		■
S. Mischler [9]		■					■	■	■	
G.E. Łazarew [10]	■	■	■	■		■		■		■
COMPLEX	■	■	■	■	■		■	■	■	

■ feature of model

(1) method of obtaining data for evaluation of reaction (wear) effects

The mechanical wear speed is calculated on the basis of a fatigue model related to a surface microroughness contact. The surface destruction mechanisms described by this model assumes that fragments of deformed microprotrusions will break away after a certain number of contact interactions (compressing and return to previous state). Such presentation of mechanical phenomena makes starting the analysis of electrochemical processes easier as there is known the size of the area of the real contact and there is a possibility to determine the moment when the "fresh" surface will be exposed. So, we know when passivation is going to start and on how big area it will occur. In the discussed algorithm there was applied a Faraday equation for evaluation of intensity of material removal in the effect of corrosive interactions. Such method is used by the majority of research workers. However, the author of the paper suggested the specific solution in which the current value necessary to carry out the calculations is determined in the analytic way. The module generating changes of current intensity was placed in the algorithm on the newly exposed surface from the moment of activation to complete repassivation. Such solution makes possible obtaining electrochemical characteristics relevant to real service conditions without necessity to make experiments. Interactions between the two elementary destructive mechanisms have been taken into account as follows:

– corrosive wear is determined only in the areas where earlier material separation occurred as a result of mechanical deformations (the influence of mechanical interactions on the course of corrosive processes),
– after each cycle of interactions the surface topography in the contact area changes; corrosive wear being here over a half of the total material loss is very important; the change of material roughness will influence the frequency and value of mechanical deformations (the influence of corrosion on the course of mechanical processes).

The total corrosive and mechanical wear is determined as an algebraic sum of both components.

In the light of problems concerning the description of contact interactions basing on average roughness characteristics the use of numerical model of microgeometry of the analysed region (figure 1) was proposed. For the use of computable procedure, it has been assumed that a rough surface can be represented by an orthogonal system of cuboids being adherent one to another. Every cuboid corresponds to a single microroughness. Heights of all microprotrusions are generated in the random way according to the assumed type of distribution (profile load carrying).

In order to forecast service changes of a rough surface there was a decision to analyse corrosive and mechanical interactions in the region of single microprotrusions. The action include:

a) localizing microprotrusions where a direct contact of co-operating elements takes place; each time a programme determines minimal coming of both surfaces ensuring mutual contact of such number of protrusions to achieve real stresses equal material microhardness,
b) determining the material loss caused by corrosive and mechanical processes occurring on the surface of microprotrusions selected in the point “a”,
c) correcting heights of microroughness respectively to the calculated total wear value.

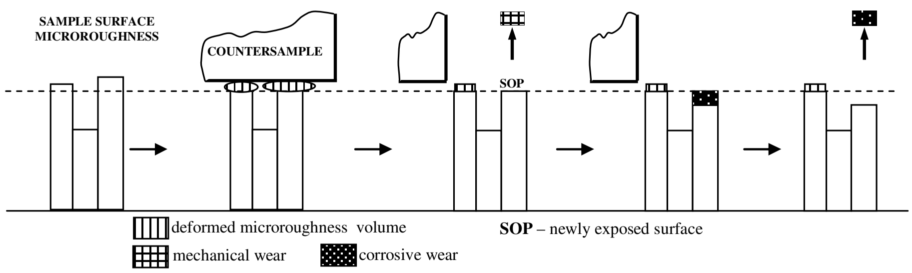

Fig. 1. Numerical model of wear region microgeometry
Rys. 1. Numeryczny model mikrogeometrii obszaru zużywania

3. Verification of elaborated model

The author used the described algorithm for elaborating the computer programme. Its effects were verified on the basis of results of experiments carried out by the team S. Mischler, D. Landolt, P. Jemmely [11]. During the tests there was used the model stand type pin-on-disc on which a non-deformed bar with a flat tip was sliding with the plane and return motion on the surface of the rectangular sample made of steel 430. Both mating elements were immersed in the sulfaric acid solution. The motion frequency was 5 Hz. The bar moved in each direction of about 2.5 mm. The action lasted 0.075 s. After reaching the next extreme location the bar stayed still for 0.025 s.

The verification data were chosen due to their following features:

a) the complex character of tests – the influence of the most important inputs (potential, stresses and kind of electrolyte) on the wear value was determined,
b) the application, in tests, of the most simplified physical model of the process – the bar did not wear.

With the use of the computer programme simulations of corrosive and mechanical wear were performed in conditions similar to those occurring during the real experiments. Making the verification the following matters were taken into consideration:

- the intensity value of complete, mechanical and corrosive wear,
- the influence of potential and stresses changes on the wear process course,
- the current intensity value on the wear surface.

The tables 2 and 3 and the figure 2 show the results of the computer simulations as well as experiments. The calculations results are respective to the system condition after 160 full motions of the bar (about 8s of operation of the pair in real conditions). During the experiments in such period of time the wear process stabilized.

Table 2. Comparison of the results of the programme and experimental data
Tabela 2. Poziomowanie zużycia wyznaczonego eksperymetalnie i przy pomocy programu

Normal stress	Applied potential	Range of measurements results	Mean value for series of measurements	Simulation results	Difference (in respect of mean value for series of measurements)
[MPa]	[V (MSE)]	[nm/cycle]	[nm/cycle]	[nm/cycle]	[%]
total wear					
45	-0.5	1.80 – 2.45	2.05	1.85	9.8
	0.5	0.8 – 1.85	1.15	1.05	8.7
8	-0.5	0.8	0.8	0.8	0
	0.5	0.3 – 0.5	0.4	0.45	12.5
corrosive wear					
45	-0.5	0.8 – 1.4	1.15	1.15	0
	0.5	0.6 – 1.2	0.8	0.7	12.5
8	-0.5	0.35 – 0.65	0.45	0.6	33.3
	0.5	0.20 – 0.30	0.25	0.30	40.0
mechanical wear					
45	-0.5	0.5 – 1.2	0.9	0.55	38.8
	0.5	0.15 – 0.75	0.35	0.4	14.3
8	-0.5	0.20 – 0.50	0.40	0.20	50
	0.5	0 – 0.15	0.05	0.10	50

Table 3. Comparison values of current intensity (+0.5 V (MSE))
Tabela 3. Porównanie wartości natężenia prądu (+0.5 V (MSE))

stress [MPa]	current intensity	
	measurement result [mA]	programme result [mA]
8	0.17–0.19	0.19
45	0.38–0.40	0.37

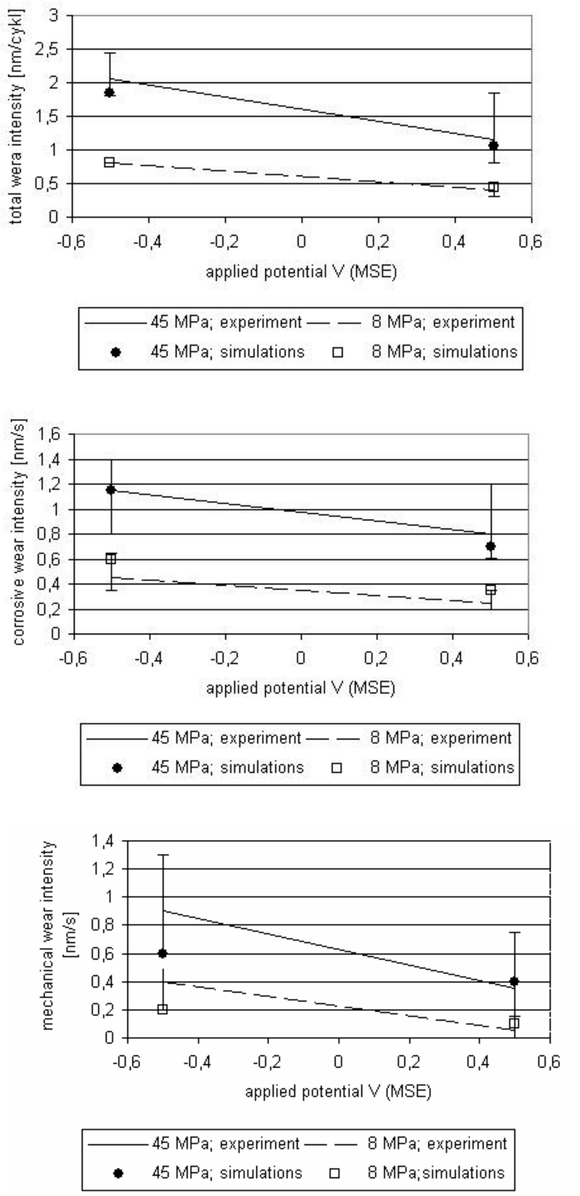

Fig. 2. Comparison of the results of the simulations and experimental data
Rys. 2. Porównanie wyników symulacji i rezultatów eksperymentów

4. Summing up

On the basis of performed analysis one can draw the following conclusions:

a) all results of calculations obtained with the use of the own algorithm are within the range determined by extreme results obtained during experiments,
b) the greatest conformation of simulation results and experimental data is obtained for the complete wear, the maximal discrepancies do not exceed 13% of mean value for the measuring series; at the present state of knowledge concerning corrosive and mechanical wear such identity should be regarded as satisfactory,
c) in the analyzed range the programme results reflect properly the influence of stresses and applied potential to the intensity of corrosive and mechanical wear; however, it should be pointed out that the application, in the programme, of the model simulating the surface roughness changes allowed for taking into account (found experimentally in operation [11]) the influence of the potential to the mechanical wear intensity,
d) in accordance with results given in the table 2 the average current intensity determined by the programme for one motion period of the bar is comparable with the value measured during the experiment.

The interpretative model of destructive mechanisms presented in this paper is not satisfactory to describe all possible forms of wear in conditions of simultaneous corrosive and mechanical interactions. So, the attempt of searching the alternative methods of mathematical description of occurring phenomena was undertaken. Models of material cracking mechanics were used assuming that the destruction of an element takes place in the effect of microslots propagation. Basing on this theory the decision was made to formulate a mathematical model allowing for forecasting the course of wear processes occurring in the steel elements volume in conditions of simultaneous corrosive and mechanical interactions. Such model is a synthetic approach of numerical description concerning:

– microslot propagation speed under the action of variable stresses (fatigue wear),
– kinetics of electrochemical processes occurring in the region of the slot "bottom" (corrosive wear).

The model of the slot corrosive propagation will be verified on the basis of results of the tensile test with cyclically variable load of samples made of austenitic stainless steel being susceptible to intercrystalline corrosion.

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Nowe możliwości obliczania zużycia korozyjno-mechanicznego w parach ślizgowych

Streszczenie

W artykule przedstawiono autorski model obliczania zużycia tarciowego metali w środowiskach elektrolitycznych. Powstał on w wyniku syntezy elementów procedur proponowanych przez różnych badaczy i algorytmu opracowanego przez autora artykułu. Opracowany własny algorytm umożliwia pełną symulację przebiegu zużywania korozyjno-mechanicznego powierzchni chropowatych w skojarzeniu pin-on-disc. Nowość w podejściu polega między innymi na symulowaniu procesu transformacji „chropowatości technologicznej w eksploatacyjną". W pracy zamieszczono również porównanie wyników obliczeń z wynikami badań eksperymentalnych. Do weryfikacji modelu symulacyjnego wykorzystano wyniki badań zespołu S. Mischler, D. Landolt, P. Jemmely [11].