CORROSION ON THE DEFORMED SURFACES

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Abstract

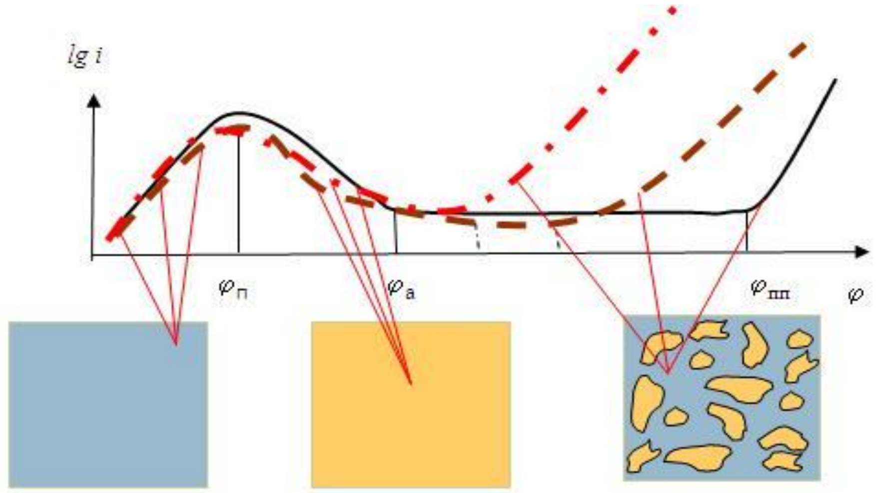
According to the electrochemical theory of corrosion wear on a surface of the metal being in hostile environment, the thin protective film is formed. Destruction of this film results in intensive corrosion wear. One of the factors promoting destruction of a protective film, deformation existence is. For definition such as deformations and its influence on a condition of a protective film three cycles of researches are executed. The analysis is carried out by an experimental and theoretical method.

Introduction

Protection against corrosion destruction of elements of designs and the constructions working in the conditions of intensive mechanical influences, is one of the most important problems of the present. Corrosion wear essentially reduces a service life and constructions that leads to technogenic and ecological failures and accidents. Especially dangerously for designs two and more sources of destruction [1-3], for example, essential mechanical tension in a combination to corrosion. Not simple addition of sources of destruction, and sometimes repeated deterioration of a situation thus takes place. In the monograph [4] exponential dependence of speed of corrosion process on tension is offered. Thus with tension growth speed of corrosion increases. In work [5] works in which influence on corrosion wear mechanical tension and defects of a material is considered are considered.

Earlier [1] the model of corrosion wear on the basis of the electrochemical theory, considering corrosion change in the presence of mechanical deformations is offered. According to the electrochemical theory of corrosion wear on a surface of the metal being in hostile environment, the thin protective film – a passivating layer [1-3] is formed. Inversely proportional dependence of intensity of electric field in a passivating layer of E_c from thickness of the last $\delta(\varphi)$ takes place. At achievement of a certain potential $\varphi = \varphi_{ПП}$ the passivating layer collapses and corrosion destruction begins. In elements of the designs perceiving loadings, the condition of a passivating layer becomes unstable – the protective film can collapse at smaller values of potential $\varphi_{ПП}$ [1-3]. That is the deformation field can promote earlier destruction of a passivating layer. The characteristic polarizing curves describing dependences of speed of i of anode dissolution from size of anode potential of φ are presented on fig. 1.

Deformation of a surface of metal at static and, especially, wave and shock loadings owing to local thinnings and violations of integrity of a passivating layer essentially influences power heterogeneity of a surface. Because of heterogeneity of a surface the ionic current passing through various sites of oxide, isn't identical, a consequence of that is locality of all properties of a passivating layer, i.e. their dependence on coordinates of a studied site on a surface. On platforms with hyperactivity the considerable density of a current is generated. On sites corresponding to them the structure of a passivating layer is weakened in a bigger measure, i.e. at smaller value of potential of φ, limiting deficiency is reached.



metal surface — formation of a passivating layer — destruction of a passivating layer

the continuous line - deformation is absent
the shaped line - static loading
the shaped with point line - dynamic loading

Fig. 1. Dependence of speed of anode dissolution on anode potential

All this promotes acceleration of corrosion process. The most active platforms become places of origin of pittings. Power heterogeneity of a surface promotes local corrosion of metals.
It is obvious that the passivating layer at deformation of an element of a design also is exposed to deformation. This factor in the electrochemical theory of corrosion wear usually don't consider.
Earlier [1] the assumption was made that the thickness of a passivating layer is determined by a formula

$$\delta_e(\varphi) = \delta\ (\varphi)\cdot(1 \mp \nu\cdot e_i \mp k_e\cdot e_i^{\,2})\cdot(1-k_y), \qquad (1)$$

where $\delta(\varphi)$– thickness of a passivating layer without mechanical deformations; e_i – intensity of deformation; ν – Puasson's factor; k_e – the factor of dynamism considering wave processes and the shock phenomena; k_y – the factor considering degree of elasticity of the passivating layer, $0 \le k_y \le 1$, to $k_y = 0$ corresponds to formation of the elastic raid, $k_y = 1$ – to formation of a fragile layer; at stretching efforts before ν and k_e the sign «-» is used, and at compressing – «+».
About an experimental and theoretical approach of research. In works [6-11] researches of corrosion wear on the stretched surfaces of thin samples free of defects and with defects in the form of scratches and dents are carried out. Thus for an assessment of degree of corrosion wear and definition of mechanical characteristics of the samples, sustained set time in hostile environment, the experimental and theoretical approach [11] is used. At an experimental stage round samples which fixed on a contour on installation were cut out from a studied thin-walled element, then them loaded with uniform pressure of River. In the course of increase in pressure of P carried out monitoring behind a dome form, in particular for top of a dome data for the schedule pressure of P are taken off - H. At a theoretical stage [11] carried out processing of experimental results for definition of the module of elasticity (at elastic deformations) or the conditional module of elasticity (at plastic deformations), using the ratios received from the nonlinear theory of covers.
About researches of group of academician Rusanov A.I. In work of [12] it is noted that for a crystal plate from *KCl* in the size of 10x5x1 mm with a relative deflection have more $f / L > 0{,}06$ (f – an arrow of the lifting, L – the characteristic size of a plate), being in a stream of *KCl* solution, speed of dissolution of the concave party during all experience more than convex.

On what surfaces there is a process of corrosion wear more intensively? The question, what deformations and as influence a condition of a passivating layer is of interest. In particular, on what surfaces there is a process of corrosion wear more intensively: on the stretched or compressed surfaces? On the one hand, the ratio (1) gives a definite answer on raised the question. However results of work of [12] testify to other. Whether specified [12] regularity remains at corrosion wear of metal elements, for example for a traditional constructional material of "steel"? Whether such phenomena, how dissolution of a crystal plate and corrosion wear are equivalent?
These questions are interesting not only to theoretical interpretation of the phenomenon, but also are very important for practice. Determination of regularities of corrosion wear will allow to project designs and constructions, it is correct to maintain them, and also to develop ways of protection of designs from corrosion wear, including it is correct to pick up sheetings. Three cycles of researches are for this purpose executed.
First cycle of researches. In the first cycle stretching and compressing deformations on surfaces of samples were created by the appendix of a magnetic field (fig. 2).

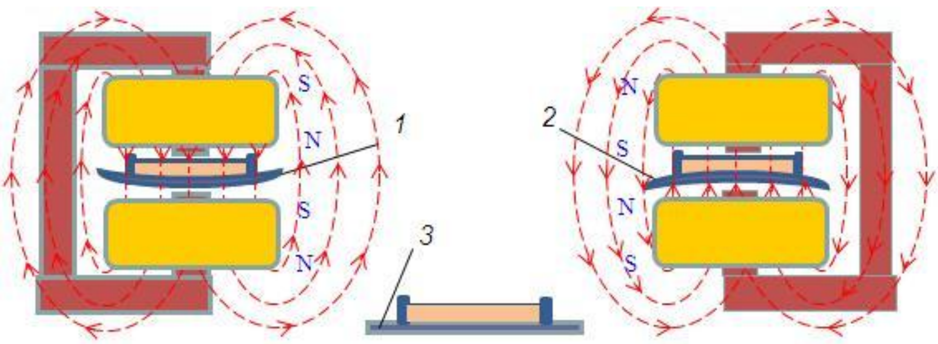


Fig. 2. Scheme of the first cycle of tests

The studied knots including samples with a superstructure for filling of their working part by aggressive liquid, fixed in three points. Under the influence of a magnetic field the concave or convex dome (a cover of double curvature) was formed: on the top surface of samples were created compressing (on fig. 2 a sample 1) or stretching (a sample 2) deformations. The top surfaces of deformable samples thus were exposed to unilateral corrosion wear during certain time. For comparison not deformable samples (on fig. 2 a sample 3) also were exposed to corrosion wear in hostile environment (10 % a chloric lime). Tested two groups of samples. Results of tests of one sample from each group are presented below.
Corrosion wear on the compressed surface. Parameters of a sample 1: radius of a working part r = 55 mm, test time in the environment of T = 840 h, including time of influence by a magnetic field of Tm = 166 h, initial thickness of t_0 = 0,75 mm, thickness of a sample after endurance in hostile environment of t_1 = 0,61 mm. Thickness of not deformed sample 3 after endurance in identical conditions in hostile environment of t_3 = 0,60 mm. On experimental data curves pressure of P - a deflection of H (fig. 3) for samples 1 and 3 are constructed.

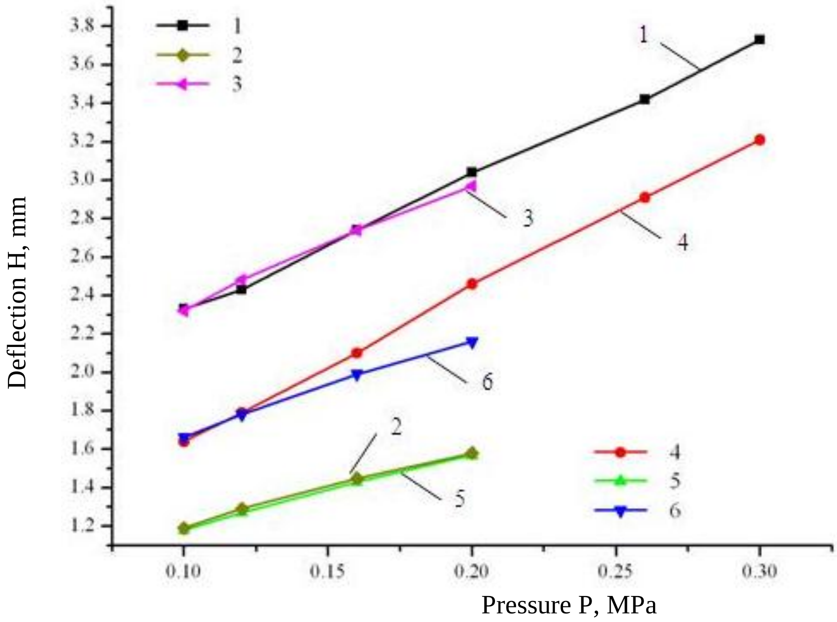


Fig. 3. Dependence of a deflection of H from pressure of P: 1–sample not deformable; 2 and 3 – calculation at E = $2.1 \cdot 10^5$ MPa and E = $3.756 \cdot 10^4$ MPa; 4–sample previously the deformed; 5 and 6 – calculation at E = $2.1 \cdot 10^5$ MPa and E = $8.981 \cdot 10^4$ MPa

Settlement values of deflection H_{1p} are given in tab. 1 for plate in thickness t_1 = 0,61 mm (corresponds to thickness of a sample 1 on fig. 2 after endurance in hostile environment). Calculations are executed at pressure of elastic deformation for the module of elasticity of E = $2{,}1 \cdot 10^5$ MPa (a curve 5 on fig. 3), and also E = $8.981 \cdot 10^4$ MPa (a curve 6 on fig. 3) which corresponds to the elasticity module for a sample 1. The curve 6 on fig. 3 as much as possible comes nearer to an experimental curve pressure of P - a deflection of H of a sample (a curve 4 on fig. 3).

Table 1. Change of deflections of samples from pressure for samples 1 and 3

P, MPa	H_{1p}, mm at E=$2.1 \cdot 10^5$ MPa	H_{1p}, mm at E=$8.981 \cdot 10^4$MPa	H_{3p}, mm at E=$2.1 \cdot 10^5$ MPa	H_{3p}, mm at E=$3.756 \cdot 10^4$ MPa
	at t_1 = 0,61 мм		at t_3 = 0,6 мм	
0.10	1.180	1.648	1.190	2.320
0.12	1.270	1.777	1.290	2.480
0.16	1.430	2.048	1.450	2.740
0.20	1.570	2.370	1.580	2.970

In the same place settlement values of deflection H_{3p} for plate in thickness t_3 = 0,60 mm (corresponds to thickness of a sample 3 on fig. 2 after endurance in hostile environment) are given. Calculations are executed at pressure of elastic deformation for the module of elasticity of E=$2.1 \cdot 10^5$ MPa (a curve 2 on fig. 3), and also E=$3.756 \cdot 10^4$ MPa (a curve 3 on fig. 3) which corresponds to the elasticity module for a sample 3. The curve 3 on fig. 3 as much as possible comes nearer to an experimental curve pressure of P - a deflection of H of a sample (a curve 1 on fig. 3). Corresponding changes of deflections from the pressure, given in tab. 1, are presented also on fig. 3.

From these tab. 1 and fig. 3 it is visible that deflections of the deformed samples it is less, than not deformed, i.e. corrosion wear on the compressed surfaces passes more slowly, than on not deformed. Change of thickness of samples testifies to it after endurance in the corrosion environment also: on samples 1 (corrosion on the compressed surfaces) we have $t_1 = 0{,}61$ mm, on not deformed samples – $t_3 = 0{,}60$ mm, means a ratio (1) is carried out. It is possible to note also that at corrosion wear occurs not only sample thinning, but also change of its module of elasticity: in the considered example for a sample 1 from E = $2.1 \cdot 10^5$ MPa to E = $8.981 \cdot 10^4$ MPa, for a sample 3 from E = $2.1 \cdot 10^5$ MPa to E=$3.756 \cdot 10^4$ MPa.

Corrosion wear on the stretched surface. Parameters of a sample 2 (fig. 2): radius of a working part r = 55 mm, the general time of test of T = 600 h, including time of influence by a magnetic field of T = 153 h, initial thickness of $t_0 = 0{,}75$ mm, thickness of a sample after endurance in hostile environment of $t_2 = 0{,}61$ mm. Thickness of a sample 3 (fig. 2) after endurance in identical conditions in hostile environment of $t_3 = 0{,}62$ mm. On experimental data curves pressure of P - a deflection of H for samples 2 and 3 (fig. 4) are constructed.

Settlement values of deflection H_{2p} are given in tab. 2 for plate in thickness $t_2 = 0{,}61$ mm (corresponds to thickness of a sample 2 on fig. 2 after endurance in hostile environment). Calculations are executed at pressure of elastic deformation for the module of elasticity of E = $2{,}1 \cdot 10^5$ MPa (a curve 2 on fig. 4), and also E = $8.577 \cdot 10^4$ MPa (a curve 3 on fig. 4) which corresponds to the elasticity module for a sample 2. The curve 3 on fig. 4 as much as possible comes nearer to an experimental curve pressure of P - a deflection of H of a sample (a curve 1 on fig. 4). In the same place settlement values of deflection H_{3p} for plate in thickness $t_3 = 0{,}62$ mm (corresponds to thickness of a sample 3 on fig. 2 after endurance in hostile environment) are presented. Calculations are executed at pressure of elastic deformation for the module of elasticity of E = $2{,}1 \cdot 10^5$ MPa (a curve 5 on fig. 4), and also E = $1.573 \cdot 10^5$ MPa (a curve 6 on fig. 4) which corresponds to the elasticity module for a sample 3. The curve 6 on fig. 4 as much as possible comes nearer to an experimental curve pressure of P - a deflection of H of a sample (a curve 4 on fig. 4). Corresponding changes of deflections from the pressure, given in tab. 2, are presented also on fig. 4.

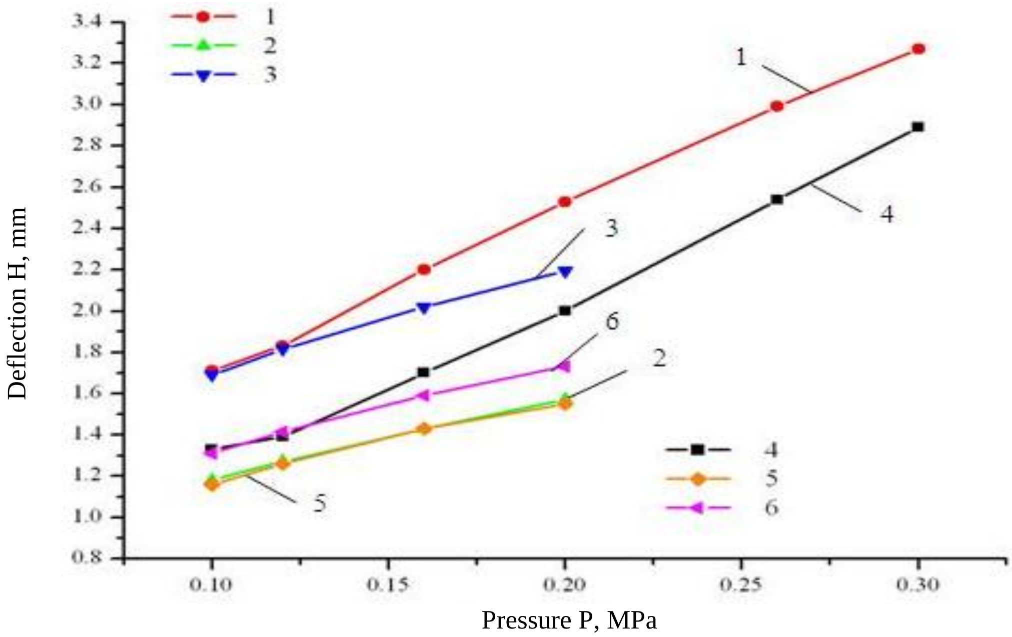


Fig. 4. Dependence of a deflection of H from pressure of P: 1–sample previously the deformed; 2 and 3 – calculation at E=$2.1 \cdot 10^5$ MPa and E=$8.577 \cdot 10^4$ MPa; 4–not deformable sample; 5 and 6 – calculation at E=$2.1 \cdot 10^5$ MPa and E=$1.573 \cdot 10^5$ MPa

Table 2. Change of deflections of samples from pressure for samples 2 and 3

P, MPa	H_{2p}, mm, at E=2.1·10^5 MPa	H_{2p}, mm, at E=8.577·10^{4}MPa	H_{3p}, mm, at E=2.1·10^5 MPa	H_{3p}, mm, at E=1.573·10^5 MPa
	t_2 = 0,61 mm		t_3 = 0,62 mm	
0.10	1.180	1.648	1.190	2.320
0.12	1.270	1.777	1.290	2.480
0.16	1.430	2.048	1.450	2.740
0.20	1.570	2.370	1.580	2.970

From these tab. 2 and fig. 4 it is visible that deflections of the deformed samples more than not deformed samples, i.e. corrosion wear on the stretched surfaces occurs quicker, than on not deformed. To it testify also change of thickness of samples after endurance in the corrosion environment: on samples 2 we have t1 = 0,61 mm, on samples 3 – t3 = 0,62 mm, the ratio (1) means is carried out. It is possible to note also that at corrosion wear occurs not only a sample thinning, but also change of its module of elasticity: in the considered example for a sample 2 from E = 2.1·10^5 MPa to E= 8.577·10^4 MPa, for a sample 3 from E = 2.1·10^5 MPa to E = 1.573·10^5 MPa.
Second cycle of researches. In the second cycle of researches for an exception of influence of a magnetic field on process of corrosion wear of stretching or compression on surfaces of studied metal samples in thickness of t_0 = 0,6 mm were created by mechanical bending, pulling together through corners opposite edges (fig. 5).

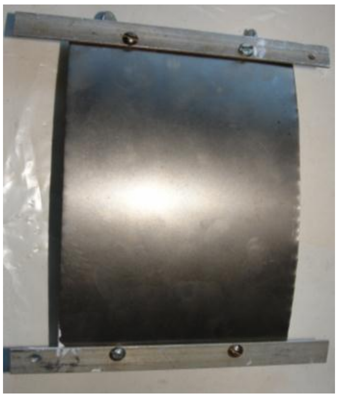


Fig. 5 Samples before test

Tightening made within elastic deformations. The relative deflection of the deformed samples made about f/L = 0,043. Thus the top (convex) surfaces of the first group of samples, bottom (bent) a surface of the second group were painted with the paint which is not dissolving in hostile environment, i.e. to corrosion subjected bottom (it is elastic compressed) surfaces of the first group of samples and top (is elastic stretched) surfaces of the second group. Samples maintained certain time (about 7 days) in the capacity filled with solution hypochloride of sodium (bleach).
The samples sustained in the corrosion environment, are investigated by means of an experimental and theoretical approach. After influence of aggressive liquid the thickness of a sample from the first group made t1 = 0,51 mm, thickness of a sample of the second group – t2 = 0,477 mm. Experimental data pressure of P - a deflection of H for samples from the first and second groups are given in tab. 3.

Table 3. Change of deflections of samples from pressure for samples of the second cycle

P, MPa	***H_1***, mm (corrosion on the compressed surface)	***H_2***, mm (corrosion on the stretched surface)
0.04	0.780	0.810
0.08	0.900	0.930
0.12	1.020	1.030
0.16	1.140	1.140
0.22	1.340	1.380
0.26	1.510	1.650
0.30	1.700	1.980

Third cycle of researches. In the third cycle investigated two groups of the samples similar to samples of the second cycle. The relative deflection is exemplary from the first f/L group = 0,075, from the second – f/L = 0,101. Initial thickness of samples of t_0 = 0,5 mm. Samples maintained during 8 days in solution hypochloride sodium (bleach). Experimental data pressure of P - a deflection of H for the considered groups of samples are given in tab. 4.

The analysis of these tab. 3 and 4 shows that deflections of samples which tested corrosion on the stretched surfaces, more than deflections of samples which tested corrosion on the compressed surfaces. Changes of thickness of samples testify to it also, i.e. corrosion wear of the stretched surfaces occurs quicker, compressed, or, in other words, the ratio (1) is carried out.

Table 4. Change of deflections of samples from pressure for samples of the third cycle

P, MPa	***H_{comp}***, mm / ***H_{stret}***, mm	
	f / L = 0,075	f / L = 0,101
0.02	0.850 / 0.900	0.860 / 0.930
0.04	0.930 / 1.000	0.950 / 1.030
0.06	1.000 / 1.100	1.040 / 1.140
0.08	1.080 / 1.220	1.120 / 1.230
0.10	1.150 / 1.320	1.200 / 1.320
0.12	1.220 / 1.430	1.290 / 1.420

Summary

Corrosion wear on the stretched surfaces, more than on the compressed surfaces.

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