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A THEORETICAL ESTIMATION OF PERFORMANCE PROPERTIES COATINGS BASED ON Fe-Cr-B-Si WITH LASER MELTING AND ALLOYING

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Abstract. *The surface hardening of laser of powder coat the system Fe-Cr-B-Si to permit lower wear of the coat. The theory of resistence of wear of the laser based an analisis strengthening of interection of atoms complex particles of the powder and detail we showed the influence of the speed of ray and diameter of stain of the laser. The theory and experiments of BNTU (Minsk) showed satisfactorily agreement for the system Fe-Cr-B-Si. This theory is the base of nanotechnology of the laser.*

Keywords: *powder metallurgy, protective powder coating.*

Alloys on iron basis have the high structural sensitivity to energetic alloying influence and alloy editions. Laser engineering allows the precise dosing of utility power and alloying materials. At the same time the nature of derivable structure specifies the quality of a strengthened layer. Moreover, the alloys have the high wear resistance as a result of composite structure.

Severization of equipment and manufacturing industry requirements to surface layers properties makes it necessary to develop composite multicomponent coatings, integrating chemical compounds of different metals in its composition. It is found that application of the mentioned protective coatings ensures the obtaining on the bearing surface the layer with high physical and mechanical properties, and performance characteristics along with good running-in ability [1, 2].

In order to develop the wear theory of the concerned coatings let us consider that all the processes of chemical bonding formation in coating and at the joint between the coating and a base proceed only in the melt spot area d_l in diameter.

The constant of quasi-chemical bonding formation rate and wear resistance consequently exponentially depend of the temperature

$$K = Y^{-1} = \frac{\tau}{\tau_a} e^{-\frac{\Delta\Phi}{kT_k}} \tag{1}$$

where $\tau = \frac{d_l}{\upsilon}$ – is the time of melt spot passing though the bonding formation zone; τ_a – is the period of atomic vibrations in metal crystal lattice; k – is the Boltzmann constant; T_k – is the temperature in the melt spot area; $\Delta\Phi$ – is the Gibbos thermodynamic potential shift to atomic volume where the formation process of running quasi-chemical bonding between particles and base is proceeded; Y – is the factor that takes into account the coating wear.

The layer temperature can be estimated as follows:

$$T_k \approx \frac{2N}{\pi\lambda d_l} \tag{2}$$

where λ – is the thermal conductivity of the coating material.

From the formula (2) it follows that we can approximately consider T_k as follows:

$$T_k \sim \frac{1}{d_l} \tag{3}$$

The thermodynamic potential shift $\Delta\Phi$ can be formularized as follows:

$$\Delta\Phi \approx \Delta\Phi_0 + \left(\frac{\partial\Phi}{\partial t}\right)_0 \cdot \tau \tag{4}$$

Let us insert formulas (3) and (4) into the equation (1), multiply the found formula by 10 and take a natural logarithm. We will get the following:

$$ln(10Y) = C_0 + C_1\tau + ln(\frac{1}{\tau}) \tag{5}$$

where the constants C_0 and C_1 can be found experimentally. Let us relate the formula (5) to the results of the experiments, i.e. to the Table 1 for the coating alloyed by molybdenum boride MoB at d_l = 1mm (x_2 = –1) and k = 1, 2 (x_3 = 1).

At load of 30 H the constants C_i are equal to the following: C_0 = 0.354, C_1 = 1.347 [1/s]. Calculations results, regarding (5) are represented in Table 1 and Figure 1. As a comparison let us study the following data: $ln(10Y_{min}) = ln(2.24) = 0.807$, $ln(Y_{max}) = ln(11.24) = 2.420$. Calculated results satisfactorily comply with the experimental results and keep within the stated limits.

Table 1

x_1	υ, mm/s	$ln(10Y_{\text{э}})$	$ln(10Y_{\text{т}})$
–1	0.8	1.445	1.815
–0.5	1.85	1.698	1.697
0	2.9	1.901	1.883
0.5	3.95	2.069	2.069
1	5	2.213	2.233

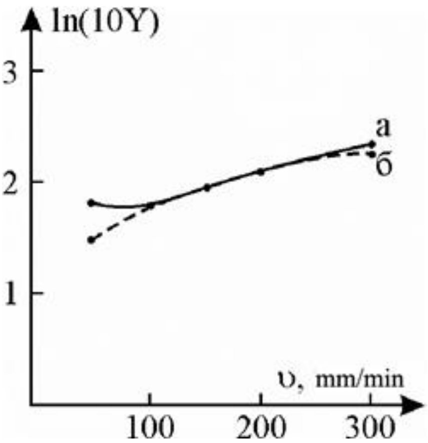

Fig. 1. a) – theory, b) – experiment

At load of 70 H the constants C_i are equal to the following: C_0 = 0.609, C_1 = 1.563 [1/s]. Calculations results are represented in Table 2 and Figure 2. As a comparison let us study the data: $ln(10Y_{min}) = ln(3.88) = 1{,}356$, $ln(Y_{max}) = ln(14.32) = 2.662$. Compliance between calculated and experimental results is also quite satisfactory.

According to our opinion considerable discrepancy between theoretical and experimental results in the area x_1 = –1 (low speeds of the spot movement) is explained by occurring of base coat submalting, however phase changes stated in the formula (4) are not taken into account.

It results from the mentioned data that miscrohardness and wear of coatings with TaB additives are influenced by Fe, Ta, CrC and VC. For the coatings with boron carbide all the ratios appeared to be insignificant. That points to the more complicated strengthening mechanism both due to matrix alloying and strengthening phase quantity. For evaluation of coatings wear we shall judge from the following considerations.

Table 2

x_1	υ, mm/s	$ln(10Y_э)$	$ln(10Y_т)$
–1	0.8	1.869	2.34
–0.5	1.85	2.069	2.069
0	2.9	2.235	2.213
0.5	3.95	2.378	2.378
1	5	2.503	2.531

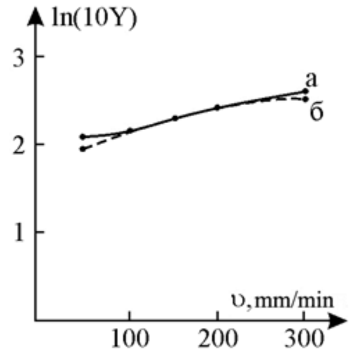

Fig. 2. a) – theory, b) – experiment.

Let us assume that layer fracture energy is as follows:

$$A_p = S_{сц} \Delta V_p \tag{6}$$

$S_{сц}$ here is adhesive strength for the coating layer and ΔV_p – is the quantity of material that was subjected to fracture.

Accordingly, the mass in this volume is the following:

$$\Delta m = \rho \Delta V_p = \rho \frac{A_p}{\sigma_{сц}} \tag{7}$$

where ρ is coating material density.

Value of wear in a unit of time can be formularized as follows:

$$I = \frac{\Delta m}{\Delta t} = \rho \frac{A_p}{\Delta t \sigma_{сц}} = \rho N \frac{1}{\sigma_{сц}} \tag{8}$$

Power consumed for ΔV_p volume fracture is the following:

$$N_p = h_p N \tag{9}$$

where the power consumed for dry friction is the following:

$$N = fP_н \upsilon \tag{10}$$

f here is a friction coefficient, $P_н$ – is a layer load and υ – is displacement speed of the layer. Finally we have the following formula for the value of wear:

$$I = \frac{\rho h_p fP_н \upsilon}{S_{сц}} \tag{11}$$

Adhesive strength can be formularized similar to (1):

$$\sigma_{сц} \approx \frac{\tau}{\tau_a} e^{-\frac{\Delta\Phi}{kT_k}} \tag{12}$$

We have:

$$T_k = \frac{b_1 \overset{\circ}{T} + b_2 T_0}{b_1 + b_2} \tag{13}$$

where heat accumulation ratios for the particle and the base accordingly are

$$b = \sqrt{\rho C \lambda}\,, \tag{14}$$

where ρ – is density, C – is thermal capacity, λ – is thermal conductivity ratio, $\overset{\circ}{T}$ – is temperature in the center of spot and T_0 – is temperature of the base. We have

$$\overset{\circ}{T} = \frac{2N_{eff}}{\pi \lambda_n d} + T_0 \tag{15}$$

N_{eff} here is laser power transmitted to the coating metal, λ_n – is coating thermal conductivity ratio, T_0 – is temperature of the base.

For the sake of calculation simplicity let us take $T_k \approx \overset{\circ}{T}$ and $\overset{\circ}{T} \sim \frac{1}{d}$. Thus from the formulas (11), (12) and (15) we receive the proximate equation for the coating wear formularized as follows:

$$lnI \approx C_0 + ln\frac{V}{d} + C_1 d + C_2 \frac{d_2}{V} \tag{16}$$

At formulizing (16) we took into account expansion of ΔΦ in series for small τ-s:

$$\Delta\Phi = \Delta\Phi_O + \frac{\partial\Phi}{\partial t} \cdot \tau \tag{17}$$

Constants C_0, C_1 and C_2 in (16) do not contain υ and d_l parameters of laser hardening. Let us consider now the comparison of the theory (16) with the BNTU experiment. For Fe without nonmetallics we have the following regression equation obtained in the course of the experiment:

$$I \sim Y = 0.722 + 0.088x_1 + 0.1x_2 + 0.135x_3 + 0.08x_1x_3 \tag{18}$$

The design method of three-factor experiment is used here. In this case parameter coding is carried out in accordance with the following:

$$x_1 = \frac{2(\upsilon - \upsilon_{max})}{\upsilon_{max} - \upsilon_{min}} + 1, x_2 = \frac{2(d - d_{max})}{d_{max} - d_{min}} + 1. \tag{19}$$

The coded value of intersection parameter is x_3. Let us hereinafter assume x_3 = 1. In BNTU experiments υ and d_l varied in the following limits:

$$0.83 \cdot 10^{-3}\, \text{м}/c \le \upsilon \le 5 \cdot 10^{-3}\, \text{м}/c, 10^{-3}\, \text{м} \le d_l \le 3 \cdot 10^{-3}\, \text{м}. \tag{20}$$

Assuming $d_l = 10^{-3}$ m and $x_2 = -1$ let us make a comparison of the experiment for Fe without nonmetallics according to (18) at $x_3 = 1$.

The results of the theory comparison are stated in the Table 3 and Figure 3.

Table 3

υ, $\times 10^{-3}$ m/s	d_l, m	x_1	x_3	$ln(10Y_э)$	$ln(10Y_т)$	$10Y_э$	$10Y_т$
0.83	10^{-3}	–1	–1	1.77	1.77	5.87	5.87
2.9	10^{-3}	0	–1	2.02	1.85	7.54	6.35
3	10^{-3}	1.05	–1	2.03	1.87	7.65	6.48
5	10^{-3}	1	–1	2.22	2.22	9.25	9.25

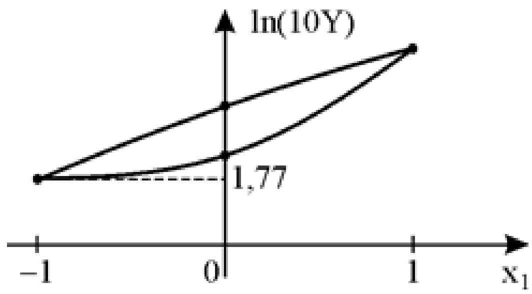

Fig. 3

Let us consider now the mathematical model of Fe-Cr-B-Si system coating wear in the case, when the coating without borides alloying is subject to laser infusion.

The experiments regarding wear of such coating, carried out by BNTU, are resulted in wear values that can be generalized by the design method of three-factor experiment:

$$Y = 0.722 + 0.088x_1 + 8.1x_2 + 0.135x_3 + 0.08x_1x_3 \tag{21}$$

In this case x_i values are formed according to (19) [3] scheme, in compliance with coding rules in three-factor model.

Using the above-stated approach we get the following results.

Table 4

υ, $\times 10^{-3}$ m/s	x_1	d_l,$\times 10^{-3}$ m	x_2	$Y_э$	$Y_т$	$ln(10Y_э)$	$ln(10Y_т)$
0.8	–1	1	–1	0.587	0.587	1.77	1.77
0.8	–1	2.0	0	0.688	0.671	1.93	1.903
0.8	–1	2.5	0,5	0.734	0.734	1.994	1.994
0.8	–1	3.0	1	0.784	0.784	2.06	2.06

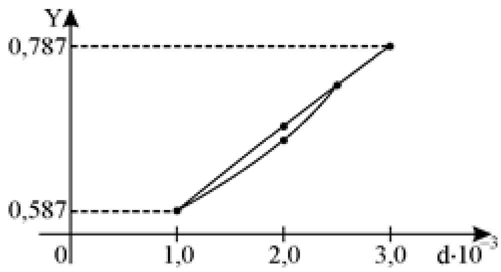

Fig. 4. Compliance of the theory (22) to BNTU experiment (21)
—— - theory, • - experiment.

The calculations were carried out by the following formula:

$$ln(10Y) \approx 0{,}898 + C_1 d + C_2 \frac{d^2}{\upsilon} + ln\frac{\upsilon}{d_l} \qquad (22)$$

where $C_1 = 1{,}228 \times 10^3$, $C_2 = -0.107 \times 10^3$.

REFERENCES

1. N.N. Dorozhkin, M.A. Kardapolova, O.V. Dyachenko, T.M. Abramovich, S.A. Donskih, Y.A. Simonov. Laser treatment influence to compaction kinetics of Fe–Cr–B–Si system coatings. Engineering and physical magazine. T.77, №4. July – August 2004. P. 92 – 95.
2. N.N. Dorozhkin, M.A. Kardapolova, O.V. Dyachenko, T.M. Abramovich, S.A. Donskih, Y.A. Simonov. Adhesive strength calculation of Fe-Cr-B-Si system adhesive coating. Published by Taganrog State Teacher's Training Institute. Mathematical models and algorithms for simulation of physical processes. Materials of International Scientific and Technical Conference. Taganrog, 2006.
3. Heat and mass exchange. Thermotechnical experiment. Reference book / E.V. Ametistov, V.A. Grigoryev, B.T. Yemzev and others. M.: Energoizdat, 1982. 512 p-s.