APPLICATION OF IONIC BOMBARDMENT FOR THE EVALUATION OF MECHANICAL PROPERTIES OF BORON-CONTAINING COATINGS

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Abstract
It is established, that the phenomena, such as a selectivity of electrical erosion with the following cleaning of the sample surface is caused by the process similar to cathode sputtering, taken place at the interaction of high voltage condensed spark with a surface of material. It is shown, that the defects, separated after the plasma cleaning, are the informative for the evaluation of mechanical properties of alloys. The advantage of ionic bombardment for the evaluation of mechanical properties of alloys as compared with known procedure of the solid particle impingement is shown. At the same time, the reliability of the process inspection is increased as much as 1,5 times in comparison with well known technology.

1. INTRODUCTION
It is recognized, that the manner of the solid particle impingement is used for the testing of the natural constructions without their failure. It is based on the existence of the correlation between the volume erosion and mechanical properties of materials. However, the technology of the solid particle impingement do not include the selectivity of the local failure of material at which the value of the volume erosion, in particular defects after the plasma cleaning, may be more informative for the estimation of mechanical properties of materials than well known procedure. The present investigation is made with the aim to use the ionic bombardment for the prediction of the mechanical properties of alloys.

2. MATERIALS AND METHODS
Boron-containing alloys were employed as the objects of the present investigation. Mechanical properties were evaluated with the relative wear resistance ε in relative units (r.u.). They were measured by the procedure [1]. The volumetric portion of structural constituents of alloys K was determined by quantitative metallographical method. The high - voltage condensed spark (HCS) from the IVS-23 generator was a source of electrical erosion of the alloys interface [2] and the excitation of AES spectra. The pulse duration of HCS was approximately 7.56 Mks. The rate of the volumetric electrical spark erosion \( \nu \) was calculated on formula \( \nu = \frac{V}{m \cdot n \cdot t} \) [2]. The \( V \) was the value of the volumetric electrical erosion, found on data of the sample weight before and after spark effect (sparkling) with the following calculation of the quantity and the volume of destructive material; the \( m \) was the initial sample mass; the \( n \) was number of sparking, in particular 10-12; the \( t \) was the single sparking duration. The relative standard deviation was 0.15-0.20. The comparison of dispersions was made by means of the F- distribution. If \( \frac{s_1^2}{s_2^2} \geq F_{0.95} (f_1, f_2) \), then the divergence between the selective dispersions \( s_1^2 \) and \( s_2^2 \) was significant at the selective level of the significance 0.95. The \( F_{0.95} \) was the quintile of the F – distribution. In contrary case the tested dispersions can be considered as belonging to the single general sample. The selective correlation coefficient was used as the indicator of the power connection between parameters.
It is known that if \( r > r_{0.95} \) (\( r_{0.95} \) is the quintile of \( r \)-distribution), then the correlation between observed values takes place. In the contrary case the correlation is absent.

3. RESULTS AND DISCUSSION

It is known, that in consequence the ionic bombardment of the electrode’s surface only a part of the energy making up 60 to 90 % from the significant stock of the energy much exceeded gasokinetic and radiant components is liberated. Moreover, complete energy of impulse is acted on the electrodes. The 10-40% of energy is dissipated in the discharge canal on the heating of gas, the radiation, the process of ionisation and others. The calculation of balance of the energy, liberated on the cathode surface at the ion braking in single spark discharge, is made [2] by a formula: \( Q = Q_1+Q_2+Q_3+Q_4 \) for the evaluation of factors contribution influencing on the process of the electrical erosion of materials. The \( Q \) is energy, transferred by means of ionic bombardment of the cathode during single spark discharge. On the other hand, the \( Q \) is spent on the energy deepened into the electrode at the cost of the thermal conduction. The surplus of the \( Q \) energy in the quantity of \( Q_2 \) is consumed on the heating, the melting and the evaporation of the metallic mass destroyed during the single spark discharge. In addition, \( Q \) energy, liberated at the ions braking on the cathode, is spent on the kinetic energy \( Q_3 \) of the torch. At last, the \( Q \) is spent on cathode sputtering equalled to \( Q_4 \). According to calculation for above-mentioned mode of HCS [2], values of the energy look out: \( Q_1=0,73\times10^{-6}\text{cal}, Q_2=0,74\times10^{-6}\text{cal}, Q_3=0,19\times10^{-6}\text{cal}, Q_4=3,34\times10^{-6}\text{cal}, Q_5=5,08\times10^{-6}\text{cal}. \) Hence, it follows that \( Q_1 = Q_2 = 15\%, Q_3 = 4\%, Q_4 = 66\% \) from \( Q \) energy liberated on the cathode. In addition, the experimental calculation of the heat emitting due to the Joule – Lens effect by the zone for example immediate to anode spot is carried out. It is shown that the heat quantity yielded on the electrodes has not exceeded \( 1,5\times10^{-5}\% \) from the energy required for the melting of the experimental established quantity of the metal. The mentioned results has demonstrated that the failure of electrodes in the investigated mode of HCS has taken place at the expense of the energy liberated on corresponding electrodes at the braking of ions and electrons. The last is agreed with Mandelshtam S.L., Buravljov Yu. M and Grikit I.A. point of view. Moreover, quasistatic phase of the erosion evaporation of the electrode zone struck by the short pulse through cathode sputtering on 66 % and only 15 % from the energy given off the electrode are spent on the erosion evaporation through the melting. In the case of the investigated mode of HCS the erosion process is called similar to cathode sputtering. Values of density of the ion current on the cathode \( \delta \), the atmosphere and its pressure \( P \) at which the discharge takes place are the characteristic features distinguishing the latest from cathode sputtering.

<table>
<thead>
<tr>
<th>Atmosphere</th>
<th>( \delta ), A/m(^2)</th>
<th>( P ), Pa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cathode sputtering [3]</td>
<td>inert</td>
<td>Max 2\times10^7</td>
</tr>
<tr>
<td>HCS [2,4]</td>
<td>air</td>
<td>( 1\times10^{10} )</td>
</tr>
</tbody>
</table>

It is known [4 ] that process of surface cathode sputtering involves the stages, such as the developing of boundaries of structural constituents of the sample microstructure and the surface cleaning . The phenomenon similar to cathode sputtering is developed by the selectivity of the electrical erosion [4] of structural constituents of materials. At the same time, it is developed by the predominant failure of boundaries of structural constituents and of the interface, such as matrix without the erosion of the primary phases. The fulfilled correlation analysis of the \( \nu= f (K) \) dependence of primary fallings out of iron borides and eutectics gives corresponding values of selective correlation coefficients such as 0,328 and 0,795 respectively at the \( r_{0.95} \) equaled to 0,378 – 0,476. Hence, it follows that only the dependence of the \( \nu \) on the \( K \) of eutectics of the matrix takes place since the \( r \) equalled to 0,795 is more than \( r_{0.95} \). In short, the fusible matrix, in particular the eutectic, is destroyed without the failure of the refractory primary fallings, such as iron borides . The surface cleaning involves the failure of the brittle structural constituents BSC and non-metallic inclusions. The increase on 12-40% (relative) of the mass part of alloying elements determined by the spectral analysis as compared with the chemical method [ 5] is the indirect development of the failure of the BSC , such as carbides, carborobides, borides, liberated upon boundaries of primary fallings out and in matrices of materials. The rise of the volumetric electrical spark erosion rate of the rustles steels, boron-containing alloys and the BSC at the decreasing of their mechanical properties is established by us [4 ]. Moreover,
results of the dispersion analysis show the predominance of electromechanical character of the spark erosion (Table 1).

Table 1. Contribution of the $\gamma$ and the E factors in the forming of intensity ($I$) of boron spectral line and the volumetric electrical spark erosion rate ($\nu$) of alloys with boride eutectics.

<table>
<thead>
<tr>
<th>The parameter</th>
<th>$s_0^2$</th>
<th>$s_\gamma^2$</th>
<th>$s_E^2$</th>
<th>$s_\gamma^2 / s_0^2$</th>
<th>$s_E^2 / s_0^2$</th>
<th>$F_{0.95}(\gamma)$</th>
<th>$F_{0.95}(E)$</th>
<th>$\sigma_\gamma^2$</th>
<th>$\sigma_E^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>I, related units (r.u.)</td>
<td>0.100</td>
<td>7.41</td>
<td>2.39</td>
<td>73.38</td>
<td>23.68</td>
<td>19.20</td>
<td>18.50</td>
<td>1.83</td>
<td>1.10</td>
</tr>
<tr>
<td>$\nu$, m$^3$ (kg·s$^{-1}$)</td>
<td>0.033·10$^{-22}$</td>
<td>2.52·10$^{-22}$</td>
<td>1.24·10$^{-22}$</td>
<td>76.27</td>
<td>37.72</td>
<td>19.20</td>
<td>18.50</td>
<td>1.24·10$^{-22}$</td>
<td>0.40·10$^{-22}$</td>
</tr>
</tbody>
</table>

Markers in Table 1 are listed lower. The $s_0^2$, $s_\gamma^2$, $s_E^2$ are dispersions, connected with the accidental error, factors of the microbrittleness $\gamma$ and the related thermal stability $E$, respectively. At the same time, the $F_{0.95}(\gamma)$ equals to 19.20, the $F_{0.95}(E)$ equals to 18.50. The $\sigma_\gamma$ and $\sigma_E$ are dispersions of influence of the $\gamma$ and the $E$ factors on the $I$ and the $\nu$ values. Tabulated results have been testified about the dominant of the $\gamma$ contribution in forming as the intensity of the spectral line as the volumetric electrical erosion rate (Table 1) of boron-containing alloys with borides of iron. Results of the dispersion analysis of $\nu$ testify the electromechanical erosion of the BSC with the different levels of its microbrittleness [4]. The rise of the rate of the volumetric electrical erosion with the increase of microbrittleness of alloyed iron borides and alloyed iron carboborides [5] is the direct confirmation of the electrical failure of BSC of boron-containing alloys. Thermal calculation of the action of the single spark discharge on surface of iron electrode is realized. The range of temperatures, exceeded the melting temperature across the time of the single spark discharge do not spread in the depth of the electrode more than 4 Mk. The effect of plane source of the heat on the surface of alloys promotes to large gradient of temperatures. It makes up 2·10$^6$ grad·cm on the depth of the single crater. Namely, it is taken place the typical accident of the thermal shock. So, at the ionic bombardment the electromechanical character of spark erosion of alloys can be explained with the thermal shock. Apparently, at the action of the thermal shock the separation of ultimate particles takes place as a result of the brittle failure of BSC, such as borides of iron, before of their melting. Then they are transported by the shock wave in the column of the discharge. The carried out correlation analysis testifies about the correlation of the value of the volumetric electrical spark erosion rate $\nu$ and mechanical properties of boron-containing coatings. Selective correlation coefficients fluctuate between 0.991 and 0.993 at the $r_{0.95}$, equaled to 0.441. At the same time, the rise of the volumetric electrical spark erosion rate of boron-containing alloys as much as 3 times at the decreasing of their mechanical properties is observed [2]. It testifies the informative of defects after the plasma cleaning, that is BSC. Then, the advantage of ionic bombardment for the estimation of mechanical properties of alloys as compared with known procedure of the solid particle impingement is shown. The mean square law deviation $S$ of measurements of the relative wear resistance on the empirical model of $\epsilon_1 = f(\nu_1)$, where the $\nu_1$ is the volumetric erosion rate, determined by the procedure of the solid particle impingement, exceeds the $S$ of measurements of the $\epsilon$ on the empirical model of $\epsilon_2 = f(\nu_2)$, where $\nu_2$ is the volumetric electric erosion rate, obtained with the ionic bombardment technology, as much as 1.7 times. At the same time, the reliability $D_\Sigma$ of the ionic bombardment process inspection is increased as much as 1,5 times in comparison with well known technology, that is:
IBLIOGRAPHY


