

Theoretical background for the creation of wear-resistant coatings at the carbo-vibro-arc hardening

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Abstract. The paper presents the results of theoretical studies that allow predicting the formation of wear-resistant coatings on the working surfaces of machine parts by the method of carbo-vibro-arc hardening (CVAH). Analytical regularities of electric field intensity formation by oscillating carbon electrode during carbo-vibro-arc hardening (CVAH) have been established; the maximum layer thickness of multicomponent paste, 2.1...2.5 mm, which ensures stable electric arc combustion during CVAH, has been theoretically substantiated. With the increase of amplitude and frequency of oscillations of the carbon electrode, the electric field strength at CVAH decreases nonlinearly, but the thickness of the hardened layer of the multicomponent paste has the greatest influence on it. As a result, ceramic-metal coatings of high quality and integrity are formed on the hardened surfaces of parts. The testing of the obtained theoretical regularities has confirmed their reliability.

1 Introduction

To increase the wear resistance of machine parts it is promising to form metal-ceramic coatings on their working surfaces [1-7]. One of the modern methods of their obtaining is carbo-vibro-arc hardening (CVAH). The first stage of the CVAH includes the creation of a uniform layer of a multicomponent paste of a certain thickness on the surface to be hardened. Then, after the paste polymerization, it is melted using a vibrating carbon electrode. The process of metal-ceramic coating formation with high physical and mechanical properties and tribotechnical characteristics is realized due to electric arc combustion [8-14].

One of the important conditions for the formation of quality metal-ceramic coatings during the CVAH is the need to ensure stable combustion of the electric arc. At the same time, research in this direction has not yet been sufficiently completed. So far, theoretical laws of formation of the electric field intensity by oscillating coal electrode during the CVAH have not been established. This, in turn, restrains the creation of a mathematical model of the CVAH process.

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2 Materials and methods

During formation of metal-ceramic coatings by the CVAH method a multicomponent paste was used containing 60% of ПIP-HX17CP4 powder, 30% of boron carbide, and the rest – cryolite. In connection with the widespread use of aqueous PVA glue solution in the CVAH coating formation processes, this solution was selected as a binder in these studies [8, 9, 11, 12, 14].

The process of forming the hardening metal-ceramic coatings was carried out on the vibro arc hardening installation (VAH-2) and consisted of two stages:

- uniform application of the paste on the samples made of alloyed steel 65G and its polymerization (temperature 80...85°C);
- the paste melting.

3 Theory / calculation

In order to form high-quality coatings during the CVAH (carbo-vibro-arc hardening) it is necessary to have a stable burning electric arc between the carbon electrode and the hardened surface with the applied paste layer. This can be ensured by creating the intensity E of the electric field exceeding the minimum threshold value. In traditional vibro arc surfacing E can be determined by the formula [15]:

$$E = k_E \cdot \frac{U_0 - U_k - U_a}{\sqrt[3]{a \cdot R^2 S^2}}, \text{ V/mm}, \quad (1)$$

where k_E – correction factor;

U_0 – supply voltage, V;

U_k, U_a – voltage losses at the cathode and anode, respectively, V

($U_k + U_a = 17 \dots 19$ V);

a – electrode acceleration, mm/s²;

R – resistance of the contact zone located between the electrode and the hardened surface, Ohm;

S – micro roughness area in the contact zone of the electrode and the hardened surface, mm².

However, dependence (1) does not take into account the placement of a paste layer between the carbon electrode and the hardened surface, which has a significant resistance [12]. Taking into account this fact, the condition of stable electric arc burning at the CVAH can be determined by the formula:

$$E = \frac{(U_0 - U_k - U_a)}{\delta(1 + k_a \sqrt[3]{a \cdot R^2 S^2})} \geq E_3, \quad (2)$$

where δ – thickness of hardened paste layer, mm;

k_a – coefficient taking into account the effect of electrode oscillations on the strength;

E_3 – the minimum value of electric field strength, which ensures stable arc combustion at the CVAH, V/mm.

The carried out research [12] found that the acceleration a can be determined by the formula (3), resistance R - by the formula (4), the area S - by the formula (5):

$$a = 4A\pi^2 f^2 = 12300 \dots 49300 \text{ mm/s}^2, \quad (3)$$

where A – oscillation amplitude of the carbon electrode at the CVAH, mm
($A = 0,5 \dots 1,1$ mm);

f – oscillation frequency of the carbon electrode at the CVAH, Hz ($f = 25$ Hz and 50 Hz).
 $R = k_{\delta} \delta^5$, Ohm, (4)

where k_{δ} – coefficient ($k_{\delta} = 28500$ Ohm/mm⁵).
 $S = 0,25\pi D^2$, mm², (5)

where D – electrode diameter, mm.
 In view of the above, expression (2) can be represented as:

$$E = \frac{(U_0 - U_{\kappa} - U_a)}{\delta(1 + 2,9 \cdot k_a \sqrt[3]{A \cdot f^2 \cdot k_{\delta}^2 \cdot \delta^{10} \cdot D^4})} \geq E_r, \text{ V/mm} \quad (6)$$

The process of sustained combustion of the arc at the CVAH (carbo-vibro-arc hardening) can be conventionally divided into three phases:

- the first phase, in which in the process of interaction of the electrode with the hardened paste layer in the creation of a potential difference $U_0 - U_a - U_{\kappa} \approx 32 \dots 42$ V there is an electric field between the electrode and the metal surface, which affects the paste layer and changes the value of its electrical resistance, resulting in an increase of conductivity, increasing current with a simultaneous decrease of resistance and voltage drop to the value U_3 , which starts the process of arc ignition;
- the second phase, in which there is a "thin" arc, the cross-section of which begins to increase, so that the resistance of the molten layer of the paste, placed between the carbon electrode and the hardened metal surface, decreases with a simultaneous reduction of the power supply voltage to U_g , at which the combustion of the arc becomes stable;
- the third phase, in which the arc cross-section, the surfacing current and the U_g source voltages are stabilized at a certain level, after which the CVAH process begins.

Determination of the coefficient k_a in dependence (6) was carried out as follows:

1) samples with different thicknesses of hardened paste layer were prepared and after ignition and the beginning of stable arc combustion the voltage values and the maximum value $\delta_{0\max}$ were recorded. Above this value the ignition and stable arc combustion could not be ensured. According to the obtained results, the corresponding values of tension E_3 were calculated:

$$E_3 = \frac{(U_0 - U_{\kappa} - U_a)}{\delta_{0\max}}, \text{ V/mm} \quad (7)$$

2) then, taking into account dependence (7), for the specified values of A , f and D , we calculated the mean values of E_3 , the corresponding mean square deviations, coefficients of variation and values of the coefficient k_a by the formula:

$$k_a = 0,345 \frac{\frac{\delta_{0\max}}{\delta_{\max}} - 1}{\sqrt[3]{A \cdot f^2 \cdot k_{\delta}^2 \cdot \delta_{\max}^{10} \cdot D^4}} \quad (8)$$

As a result of the calculations, the average value of the coefficient k_a was 10^{-6} .

Analysis of the results of studies of the electric field E_r intensity for the considered composition of multicomponent paste showed that the value of the E_r practically does not depend on the ratio of the paste main components in the considered ranges of their variation. The mean square deviation and the coefficient of variation are, respectively, 0,26 V/mm and 8,5%, which is generally very insignificant.

Therefore, dependence (6) can be written:

$$E = k_g E_0 \geq E_{r(\max)} = 3,9 \text{ V/mm}, \quad (9)$$

where k_g – coefficient, defined according to the formula:

$$k_g = (1 + 2,9 \cdot k_a \sqrt[3]{A \cdot f^2 \cdot k_\delta^2 \cdot \delta^{10} \cdot D^4})^{-1} \quad (10)$$

E_0 – field strength at the non-oscillating electrode:

$$E_0 = (U_0 - U_\kappa - U_a) / \delta, \text{ V/mm} \quad (11)$$

Graphical dependences of intensity E on the thickness δ of the hardened paste layer at amplitudes and frequencies of oscillations of the carbon electrode, $A = 0.5$; 1.1 mm and $f = 25$; 50 Hz, respectively, are shown in fig. 1.

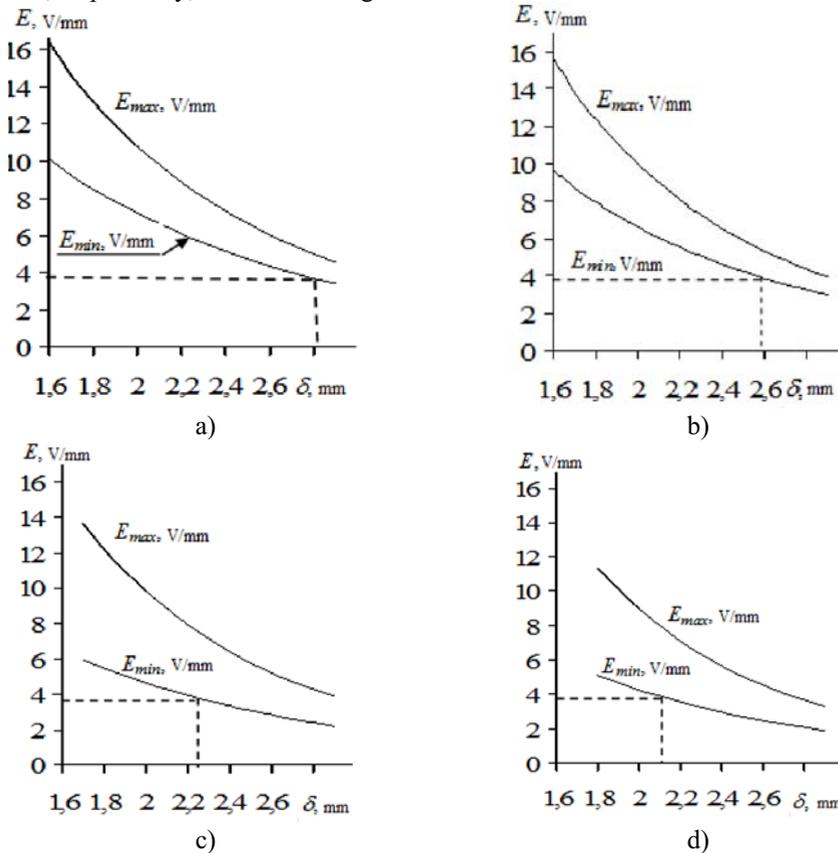


Fig. 1. Dependences of maximum E_{max} and minimum E_{min} electric field strength on the thickness δ of the hardened paste layer at electrodes oscillations with amplitude $A = 0.5$ mm (a, b) and frequency $f = 25$ Hz (a) and $f = 50$ Hz (b) and with amplitude $A = 1.1$ mm (c, d) and frequency $f = 25$ Hz (c) and $f = 50$ Hz (d)

Data analysis of fig. 1 shows that increasing the amplitude and frequency of oscillations of the carbon electrode leads to reducing the thickness of the hardened layer of the paste

which is acceptable for stable arc combustion. In the range of amplitudes and frequencies of oscillations of the carbon electrode it corresponds to $\delta = 2.1...2.8$ mm.

In this case, one of the factors limiting the thickness of the hardened layer of the paste can be attributed to the stability of the arc ignition process, since the stable arc combustion is ensured even at high values of the thickness of the paste hardened layer. This is mainly due to the fact that during stable arc combustion its cross-section increases, approaching the cross-section of the carbon electrode, and resistance, respectively, decreases, which leads to a decrease in the electric field strength. Therefore, given the data presented in [12], the values $\delta = 2.1...2.5$ mm can be referred to the most rational thickness of the hardened paste layer from the position of arc ignition and combustion.

4 Results and discussion

When testing the theoretical modeling results, which ensure stable combustion of electric arc during the CVAH, the following was established. When a 2.1...2.5 mm thick layer of the multicomponent paste is created on the hardened surface, the electric arc ignites and burns steadily, which leads to the formation of a high integrity and quality metal-ceramic coating (fig. 2, a). If the thickness of the paste layer increases to 2.8...3.0 mm, the electric arc burns very unstable and a uniform high-quality metal-ceramic cover is absent in this case (fig. 2, b). Increasing the thickness of the passive layer over 3.0 mm makes it impossible to ignite the electric arc.

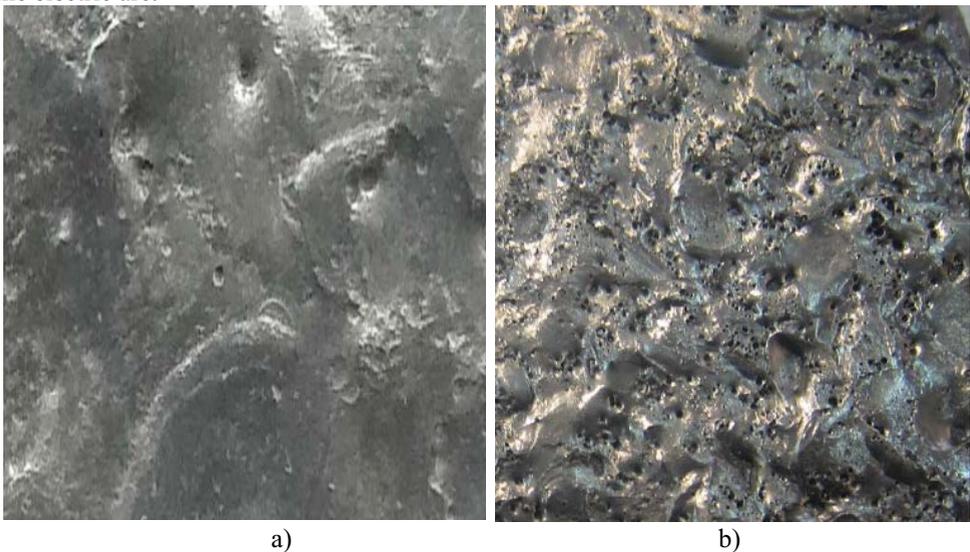


Fig. 2 – High-quality metal-ceramic coating with high integrity (a), formed with a layer thickness of the multicomponent paste 2.4 mm, and low-quality coating (b), formed with a layer thickness of paste 2.9 mm

5 Conclusions

Theoretical regularities of electric field intensity formation by oscillating carbon electrode during the CVAH (carbo-vibro-arc hardening) have been established. The maximum thickness of the multicomponent paste layer of 2.1...2.5 mm, which ensures stable electric arc combustion at the CVAH, has been theoretically substantiated. It is established that with increasing amplitude and frequency of oscillations of the carbon electrode the electric field

intensity at the CVAH decreases nonlinearly, however, the thickness of the hardened layer of the multicomponent paste has the greatest influence on its value. The testing of the obtained theoretical regularities confirmed their reliability.

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