EFFECT OF PULSE CURRENT FREQUENCY ON THE
FORMATION OF A REINFORCED LAYER
IN ELECTRIC-SPARK ALLOYING

A. D. Verkhoturov, A. M. Paramonov, and V. T. Bondar

The electric-spark alloying (ESA) method is being increasingly used in industry [1]. However, the low productivity of the process and lack of suitable mechanized equipment considerably restrict its range of practical applications. In surface reinforcement by the ESA method it is usual to employ a vibrating electrode, so that the frequency of pulse current passage through the spark gap is determined by the electrode vibration frequency. With nearly all series-produced machines the electrode vibration frequency is 100 Hz.

The basis of ESA is a pulsating action of highly concentrated energy fluxes (current pulses) on electrodes. The current-pulse time characteristics of the most widely used series-produced Soviet units, models ÉFI-10 and ÉFI-46, are as follows: pulse frequency \( f = 100 \) Hz and pulse duration \( T = 100 \) \( \mu \)sec. Thus, the reciprocal of the pulse duty factor, i.e., the ratio of the pulse current period to the pulse duration, is given by the expression

\[
Q = \frac{1}{fT} ; \quad Q = \frac{10^6}{10^2 \cdot 10^2} = 100.
\]

Clearly, one of the most obvious ways of increasing ESA productivity, which has not yet attracted sufficient attention, is to decrease this quantity by increasing the pulse current frequency. It must, of course, be borne in mind that increasing the frequency of the pulse current raises, other things being equal, the temperature of the electrodes in the treatment zones, which cannot fail to affect the character and structure of the reinforced layer [2], but so far no data concerning this aspect have been reported in the literature.

In this article the results are presented of an investigation of some key properties of reinforced layers produced by alloying with the pure Groups IV-VI elements Zr, Nb, Mo, and W in an ÉFI-22 fine-alloying unit [2]. Pure metals were chosen as electrode materials because they constitute convenient model objects for investigating the effect of the nature of the alloying electrode material on the process of formation of a reinforced layer. As cathodes, specimens of 4-cm² area (20-mm-square, 10-mm-thick) in U₈ steel,* which is widely used in tool manufacture, were employed. Alloying was performed at \( U_m = 80 \) V, \( C = 8 \) \( \mu \)F, and fixed frequencies of 250, 400, 770, and 1000 Hz. The anode area was 1 cm² (the anodes were 10 mm square and 25 mm long).

The experimental procedure was chosen so as to make it possible not only to determine the effect of pulse current frequency on the formation of reinforced layers but also to find out which of the electrodes (anode or cathode) is associated with processes responsible for any changes in coating formation regularities. This was achieved by measuring the weight changes of both electrodes after 2-min alloying (the specific alloying time was 0.5 min/cm²) and thus studying simultaneously the processes of coating formation on the cathode and anode erosion.

Determination were made of cathode weight changes as functions of time of alloying at various frequencies and of the corresponding weight changes of the anode materials investigated (Figs. 1-4). In addition, the results shown in Figs. 1-4 were processed mathematically in order to determine the effect of pulse current frequency on the intensity of anode erosion, the cathode weight gain, and the transfer coefficient (ratio of the cathode weight gain to the anode weight loss). The calculated characteristics are given in Table 1.

* A 0.8% C grade — Translator.

Fig. 1. Variation of anode (W) erosion and cathode (U8 steel) weight gain with time of alloying at various pulse current frequencies: 1) 400; 2) 770; 3) 1000 (without specimen cooling); 4) 1000 Hz (with specimen cooling).

Fig. 2. Variation of anode (Nb) erosion and cathode (U8 steel) weight gain with alloying time: 1) 250; 2) 400; 3) 770; 4) 1000 Hz.

Fig. 3. Variation of anode (Mo) erosion and cathode (U8 steel) weight gain with alloying time: 1) 400; 2) 1000 Hz.

Fig. 4. Variation of anode (Zr) erosion and cathode (U8 steel) weight gain with alloying time: 1) 250; 2) 400; 3) 770; 4) 1000 Hz.

**TABLE 1. Relative Values of Anode Erosion, Cathode Weight Gain, and Transfer Coefficient at Various Pulse Current Frequencies**

<table>
<thead>
<tr>
<th>Anode material</th>
<th>Anode erosion at freq., Hz: 400:770:1000</th>
<th>Cathode wt. gain at freq., Hz: 400:770:1000</th>
<th>Transfer coeff. at freq., Hz: 400:770:1000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mo</td>
<td>1:1.67:3.18</td>
<td>1:2.50:6.57</td>
<td>0.25:0.38:0.53</td>
</tr>
<tr>
<td>Nb</td>
<td>1:1.76:3.76</td>
<td>1:2.03:2.81</td>
<td>0.18:0.22:0.14</td>
</tr>
<tr>
<td>W</td>
<td>1:1.34:2.00</td>
<td>1:1.57:2.50</td>
<td>0.40:0.47:0.50</td>
</tr>
<tr>
<td>Zr</td>
<td>1:1.65:3.06</td>
<td>1:6.80:13.0</td>
<td>0.15:0.61:0.58</td>
</tr>
</tbody>
</table>

The intensities of erosion of the molybdenum and niobium anodes were practically independent of alloying time, but were quite strongly affected by pulse current frequency. When the frequency was changed from 400 to 770 and 1000 Hz (frequency ratio 1:1.92:2.5), the intensities of erosion of the molybdenum anode after 20-min alloying were in the ratio 1:1.67:3.18 and those of the niobium anode after 7-min alloying in the ratio 1:1.65:3.06 (Table 1).

The intensities of erosion of the tungsten and zirconium anodes as functions of alloying time decreased, but their variation was more complex in character. The intensities of erosion of the anodes as functions of pulse current frequency increased in the ratios 1:1.34:2.0 (W) and 1:1.65:3.06 (Zr). Further investigations and an analysis of the results obtained revealed that the complex character of the erosion vs time relationship for the tungsten electrode was due to a fall in the amount of brittle products in the erosion debris brought about by the temperature in regions adjacent to the treatment zone rising to 300–500°C, i.e., above the cold-brittleness threshold. The fall in erosion intensity exhibited by the zirconium electrode was largely due to the formation of the nonconducting oxide ZrO₂ on the surface being treated, as a result of which the number of spark discharges decreased. During experiments, after a certain time of alloying periodic breaks of up to 3- to 7-sec duration were observed in the generation of spark pulses. This phenomenon coincided in time with an appreciable heating up of the electrodes.