Provision of wear resistance and fatigue strength of surfaces during electroerosive processing

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Abstract. This article is a generalization of the results of theoretical studies of the effect of erosion control regimes on the operational properties of mold-forming parts of molds. The main problem is the provision of wear resistance and fatigue strength in the electroerosion processing of these types of products. The analysis showed that the fatigue strength is affected by the processing regimes and the coefficient after the erosion treatment. The index of wear resistance is determined both by the treatment modes and by the physical-mechanical properties of the billet materials. To ensure the operational performance of products, it is necessary to establish the physical picture of the processing of complex profile parts by finding the optimum eroding regime.

1. Introduction

Among all the known methods of plastic processing, one of the most difficult tools in terms of the tool used is injection molding. When manufacturing parts by this method, it is necessary to design and produce a mold for each part (or group of parts).

The main purpose of the molds is to use them during the injection molding of metals, as well as polymers, casting on melted models or pressing materials from the polymer. In one mold, simultaneous production of several parts is possible. To form-forming parts, such as combs, high demands are placed on the accuracy and roughness of the surface, as well as the requirements for achieving specified performance properties. Form-forming parts provide the desired shape of the resulting products. This type of mold parts is most prone to wear, since the working period of one mold is about 600 to 700 thousand cycles.

The combs have a complicated profile contour, which by traditional methods is rather difficult to obtain. In view of this, the most effective method of obtaining these surfaces is electroerosive treatment.

The processes occurring during the electroerosion processing have been studied in detail, the influence of technological treatment regimes on the quality of the surface layer, the accuracy, wear of the tool electrode, and the productivity of the process have been revealed [1-6]. In the electroerosive processing of composite parts in the surface layer of the material, residual stresses arise which cause the forming elements to break and the mold to break.

One of the solutions to this problem is to provide the required wear resistance and fatigue strength by finding the optimum erosion control regimes.
2. **Materials and methods**

The task, which is solved with the provision of wear resistance and fatigue strength, is the establishment of cutting modes in the process of electroerosion processing, which will not worsen the performance of the product.

Form-forming elements are working bodies of the mold, which are designed separately, but guided by the technical parameters and capabilities of the machine as a whole. The combs (Figure 1) have a complex profile contour, which is difficult to obtain by traditional processing methods. In such cases, an electro-erosion treatment is used. With this method, you can process solid parts with projections and cutouts of complex configuration.

The following technical requirements are imposed on the mold-forming parts of the molds:

1. On the surface of the parts, there should be no traces of corrosion, cracks and other mechanical damages that impair strength, performance and appearance.

2. The roughness of the mold cavities of the mold parts should correspond to a value of 0.20 μm; forming cavities for products of lighting engineering and for products with surfaces for galvanic or vacuum metallization - 0.025 microns. In technically justified cases, it is allowed to perform forming surfaces with roughness Ra ≤ 0.40 μm.

3. Dimensions and roughness of the forming surfaces with a coating should be indicated in the drawings for these parts after coating.

4. Mold-forming surfaces of mold parts, depending on the polymer material to be processed, must be subjected to one of the types of galvanic, chemical or chemical-thermal treatment: chrome plating, nickel plating, nitriding, oxidation, etc. The thickness of the chromium layer must be at least 12 microns. In hard-to-reach places, the thickness of the chromium layer is not less than 6 μm.

5. Shape-forming surfaces should be polished before and after galvanic, chemical or chemical-thermal treatment.

\[\text{Figure 1. A general view of the "comb" part}\]
6. Polishing in runners and sprues is advisable to carry out along the mass flow and in the direction of removal of the part.

The combs perform a responsible function in the operation of any mold or die. On a comb print, the finished part is obtained with the specified accuracy and roughness. When designing a comb, the accuracy and roughness indices are 1 to 2 classes higher than the resulting part. When operating the mold, the most vulnerable to wear and the risk of breakage is the comb. To ensure the established life and performance indicators of this part, it is necessary to establish the interrelation of the processing modes with the required operational parameters (wear resistance and fatigue strength) at the stage of designing the technological process of electroerosive machining.

3. Obtaining the theoretical dependences of fatigue strength and wear resistance with the modes of electroerosion machining.

Fatigue strength is the property of the material not to be destroyed over time under the influence of changing workloads. Destruction occurs due to the appearance of microcracks, their accumulation, then merging into one macro-destruction. In the electroerosion treatment of complex profiles in the surface layer, residual stresses are formed, which leads to the appearance of microcracks. To solve this problem, it is necessary to provide such modes of electroerosion processing, which will not worsen the fatigue strength parameters.

The fatigue resistance is characterized by the stress concentration coefficient, which is calculated by the formula [7]:

$$\alpha_\sigma = 1 + \frac{200}{t_m S_m} \left[2\gamma R_{\text{max}}(R_{\text{max}} - R_p)\right]^{0.5} \quad (1)$$

where $R_{\text{max}}$, $R_p$, $S_m$ – roughness parameter, $t_m$ – relative reference length of the profile at the midline level, $\gamma$ – coefficient after electroerosion treatment, which must be determined as a result of experimental studies.

In turn, the parameters of roughness in the electroerosion processing can be calculated from the theoretical relationships [8]:

$$R_{\text{max}} = \sqrt{(2\beta - 1)I U \eta \tau} \quad (2)$$

$$R_p = 0.671 R_z \quad (3)$$

$$R_z = 0.84 \cdot \sqrt{(2\beta - 1)I U \eta \tau} \quad (4)$$

$$S_m = 4.5 R_z \quad (5)$$

$$t_m = 0.49 p^{1.02} \quad (6)$$

where $\beta$ - overlap factor of the wells, $I$ – amperage, $U$ – voltage applied to the electrodes, $\eta$ - coefficient of useful energy of pulse, $\tau$ – pulse duration, $c$ – specific heat of material, $\rho$ - material density, $T_{\text{me}}$ – melting point of material, $p$ – level of section (50%).

Substituting equations (2-6) into equation (1), one obtains:

$$\alpha_\sigma = 1 + \frac{200}{26.49 \cdot 3.78 \cdot \sqrt{(2\beta - 1)I U \eta \tau} \cdot \sqrt{\left[2\gamma \frac{(2\beta - 1)I U \eta \tau}{\sqrt{(4\beta + 1) c \rho T_{\text{me}}}}\right]^{0.5}} = 1 + \frac{1.867^{0.5}}{\sqrt{(2\beta - 1)I U \eta \tau} \cdot \sqrt{(4\beta + 1) c \rho T_{\text{me}}}} \quad (7)$$

Thus, it can be concluded that the fatigue strength depends on the strength of the current, the voltage applied to the electrodes and the duration of the pulses.
Let us consider the second operational indicator - friction and wear.

Wear resistance is an operational property that determines the ability of the surface layers of parts to resist fracture during friction-sliding, friction-rolling, and also with micro-displacements caused by vibration. Friction and wear of parts are largely determined by the shape and height of the roughness, and by the direction of the processing strokes.

To evaluate the quality of friction surfaces, a parameter characterizing the equilibrium state of friction surfaces is proposed [9]:

\[
C_x = \frac{(RaWzH_{max})^{1/6}}{t_m^{1/2}S_m^{1/2}u_{cw}^{1/2} \lambda}
\]  

(8)

where \(H_{max}\) – surface macro deviations \(W_z\) – surface waviness, \(Ra, S_m\) – surface roughness parameter, \(t_m\) – relative reference length of the profile at the midline level, \(u_{cw}\) – surface layer degree of cold hardening, \(\lambda\) – coefficient that takes into account the effect of surface residual stresses of the second kind on wear.

Surface waviness can be calculated using the theoretical relationship [8]:

\[
Wz = 0.5 \cdot \sqrt{\frac{I \cdot \eta \cdot \tau}{c \cdot \rho \cdot T}} \cdot \left(\frac{1}{\sqrt{U_{max}}} - \frac{1}{\sqrt{U_{min}}}\right)
\]

(9)

where \(I\) – amperage, \(\eta\) - coefficient of useful pulse energy, \(\tau\) – duration of pulses, \(c\) – material specific heat, \(\rho\) - material density, \(T\) – material melting point, \(U_{max}\) – maximum stress during machining, \(U_{min}\) – minimum stress during machining.

The degree of cold hardening of the surface layer is determined by the formula [10]:

\[
U_H = \frac{H_h - H_s}{H_h}
\]

(10)

where \(H_h\) – cold-hardened layer microhardness, \(H_s\) – starting material microhardness.

In its turn, the microhardness of the starting material in the electroerosion processing is determined by the formula [8]:

\[
h_h = 10^{-3} \cdot \frac{A_p^{0.234} \cdot \Pi_l^{0.409}}{\Pi_d^{0.236}}
\]

(11)

where \(A_p\)–pulse energy, \(\Pi_l\)–Palatnik phase transformation coefficient of the part material, \(\Pi_d\)–Palatnik phase transformation coefficient of the tool material.

The coefficient that takes into account the effect of surface residual stresses of the second kind on wear is determined by the formula [9]:

\[
\lambda = \left(\frac{\delta_e - \delta_{re}}{\delta_{am}}\right)^t
\]

(12)

where \(\delta_e\) – temporary fracture resistance, \(\delta_{am}\) – effective value of the amplitude stress on the friction surface, \(t\) – parameter of frictional fatigue at elastic contact.

Substituting equations (2-6), (9-12) into equation (8), one obtains:
Thus, it can be concluded that the wear resistance depends on the modes of electroerosion processing.

4. Conclusions

In the course of the theoretical studies, functional dependences of performance indicators (fatigue strength and wear resistance) on the conditions of electroerosion treatment were obtained. Fatigue strength depends on the strength of the amperage, the voltage applied to the electrodes and the duration of the pulses. Wear resistance also depends on the treatment modes and on the physical and mechanical properties of the workpiece materials. Since, for different variations in the values of amperage, voltage, and pulse width, one can obtain the same value of performance indicators, it is necessary to carry out experimental studies to provide fatigue strength and wear resistance by finding the optimum electroerosion mode.

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