Mathematic modeling of detail's restoration combined process

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Abstract
The process of restoration when frayed surface of machine details covering with layer of required thickness with predefined properties that allows to effectively solve the problem of prolongation of service life of machine details is considered. As a research method, the mathematical modeling of electrocontact hardening of the sprayed powder layer is chosen.

Keywords: FRAYED DETAILS, ELECTROCONTACT HARDENING, GAS-THERMAL SPRAYED POWDER LAYER, MATHEMATICAL MODEL

Modern industry uses a great number of parts of mechanisms and machines subjected to significant loads during operation. Production experience of repair enterprises [1-6] shows that the quality of the recovered parts, lost their original service characteristics, similar to newly manufactured, is defined by used technologies and depends on the reliability of the technological process in general. Thus, to coat a layer of material whose thickness is commensurable with the value of wear, we use technologies of protective coatings. And hybrid restoration methods takes the significant place among them. The main disadvantage of coatings is their low adhesive and cohesive strength [7-11, 16-18]. This is connected with non-significant parameters of the gas pressure and low velocity of particles of coated materials in the coating formation zone. Improving the quality performances of gas-thermal coatings can be achieved by introducing into the technological process additional strengthening recovery operation – electrical contact treatment [12, 13]. However, the peculiarities of the formation of the reinforcing layer have not been studied enough. The main assumption in the modeling of electrical contact hardening of sprayed coatings is absence of longitudinal ε_l and transverse ε_b deformations of sprayed layers, on the basis of the condition of preserving the integrity of hardening composition

$$\varepsilon_l = \varepsilon_b = 0, \tag{1}$$

that is on its kinematics corresponds to a process of powder consolidation in a closed matrix [14, 15, 19-21]. Using the methodology of the technological scheme calculation and carrying out decomposition of the deformation centre into a finite set of elementary volumes, the current values of normal σ_{xi} and normal contact

P_{xi} stresses can be defined as

$$P_{xi} = \sigma_{sxi}/3\sqrt{\left[(1+4\alpha_{xi})/\alpha_{xi}\right]\cdot\beta_{xi}} \tag{2}$$

$$\sigma_{xi} = (1-2\alpha_{xi})/(1+4\alpha_{xi})P_{xi} \tag{3}$$

where α_{xi}, β_{xi} – are the current values of the condition coefficients of hardening gaz-sprayed layer plasticity; i – is the ordinal number of the deformation centre cross-section; σ_{sxi} – is the current value of the yield point of the sprayed layer solid phase, taking on during hardening by variable value along the length of the deformation zone and functionally determined depending on the current value of the equivalent plastic deformation ε_{ex}

The current value of the equivalent plastic deformation in this case, may be defined as follows

$$\varepsilon_{\text{э}xi} = 1/3\sum_{i=1}^{k}\beta_{xi}^{1/2}(4+1/\alpha_{xi})^{1/2}\,\Delta\gamma_{xi}/\gamma_{xi}^{2} \tag{4}$$

where k – is the ordinal number of the analyzed section; $\Delta\gamma_{xi}$ – is the relative density increment obtained during the transition from (i-1) to i elementary section.

The current value of the relative density γ_{xi}, knowledge of which is necessary to determine according to (4) the equivalent plastic deformation, can be determined directly from the condition of the mass conservation

$$\gamma_{xi} = h_0\,\gamma_0 / h_{xi}, \tag{5}$$

where h_0, γ_0 – are the initial indexes of thickness and relative density; h_{xi} – is the current value of the hardening composition.

Besides the above-mentioned facts an assumption was adopted in the mathematical model, that the tangential contact stresses in the hearth of deformation are subjected to Coulon-Ammonton friction law, i. e. $\tau_x = f_x P_x$, with the analytical descriptions of the contact friction coefficient distributions for the lagging and advance zones can be presented by the power dependences of the following forms

$$f_{x1(2)} = f_{lag1(2)}\left[\frac{x - l_{lead1(2)}}{l_{pl} - l_{lead1(2)}}\right]^{a_{f1(2)}}$$

with $l_{\text{lead1(2)}} < x \le l_{\text{pl}}$; (6)

$$f_{x1(2)} = f_{lag1(2)}\left[\frac{l_{lead1(2)} - x}{l_{lead1(2)}}\right]^{a_{f1(2)}}$$

with $0 < x \le l_{\text{lead1(2)}}$, (7)

where x – is the geometrical coordinate, having its origin in the plane of the interface of consolidation zone and elastic recovery zone; $f_{\text{lag1(2)}}$, $f_{\text{lead1(2)}}$ – are the reference values of friction coefficients, corresponding to the values of these coefficients in the cross section at the inlet (x=l_{pl}) and in the outlet section (x=0) from the consolidation zone; $a_{f1(2)}$ – is the power performances characterizing the shape of diagrams of the friction coefficients distribution along the length of the contact surfaces on the roller electrode and the reinforcing layer, respectively.

In terms of the initial conditions, the calculated values of the stresses σ_x, in turn, must be equal to the known stresses of front tension or backwater σ_1. Achieving of this condition, in turn, was ensured by the directional iterative change of relative length in the advance zone on the roller electrode $S_{l1}=l_{\text{lead1}}/l_{\text{pl}}$:

$$S_{l1(k+1)} = S_{l1k} + A_S\,sign\{\sigma_{xABk} - \sigma_1\} \tag{8}$$

where k – is the ordinal number of the next iteration loop; A_S – is a step of change in the relative length of the advance zone, the value of which, depending on the degree of approximation to the desired result was adopted as a variable; sign $\{\sigma_{xABk}-\sigma_1\}$ – is the gradient estimation of direction increment.

Based on the used quantitative assessment S_{l1}, and also based on the known value of the performance of kinematic asymmetry degree $K_V = V_{B1}/V_{B2}$, determined also the value of relative length of the advance zone on the roller electrode

$$S_{l2}=\frac{l_{lead2}}{l_{pl}}=\sqrt{\frac{h_1(K_V-1)}{h_0-h_1}+K_VS_{l1}^2} \qquad (9)$$

After determining the mode of deformation in the deformation centre we determine the value of compression strength

$$P=b\sum_{i=2}^{K_R}\frac{p_{x2(i-1)}+p_{x2i}}{2}\Delta x \qquad (10)$$

and the total moment on the roller

$$M=2Rb\sum_{i=2}^{K_R}\frac{p_{x2(i-1)}f_{x1(i-1)}+p_{x2i}f_{x2i}}{2}\Delta x \qquad (11)$$

The above-mentioned descriptions made the full algorithm on mathematical simulation of the process of the sprayed layer electric contact hardening. As an example of the developed mathematical model we obtained calculated dependences of the local characteristics of the process at electric contact hardening of coating, spread on parts of steel St3 by working layer of powder material PT-NA-01 (Fig. 1). From the analysis of the calculated distributions of integral characteristics for the hardening process, depending on the radius of the restored surface we see, that with an increase in the asymmetry degree of the process there is a slight increase in power and in moment with some reduction in power of electric contact hardening (Fig. 2).

Also there are the calculated dependences of the level of maximum contact stresses and final relative density of sputtered layer on the degree of deformation.

These dependences can be used for optimal technological modes development under the given levels of physical and mechanical properties of the layer and the integral characteristics of the process (Fig. 3). From the analysis of the presented dependencies we can see that the stresses distribution is rather complex. In particular, the distribution of tangential contact stresses shows that in the centre of deformation the lagging zone prevails. Maximum of normal contact stresses is observed at the output of the deformation source.

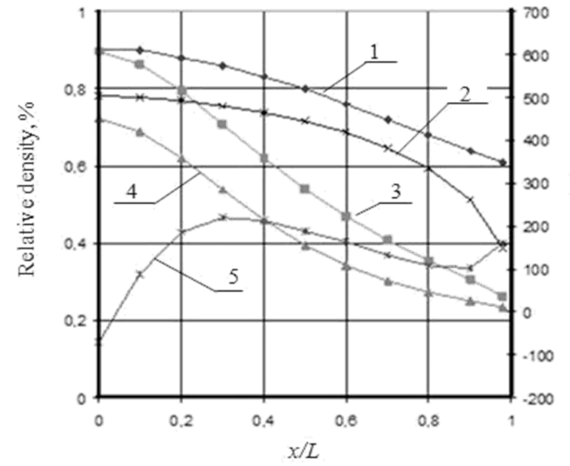

Figure1. The calculated distributions of local features for stress state:

1 – relative density; 2 – yield strength; 3 – normal contact stresses; 4 – normal stresses; 5 - tangential contact stresses

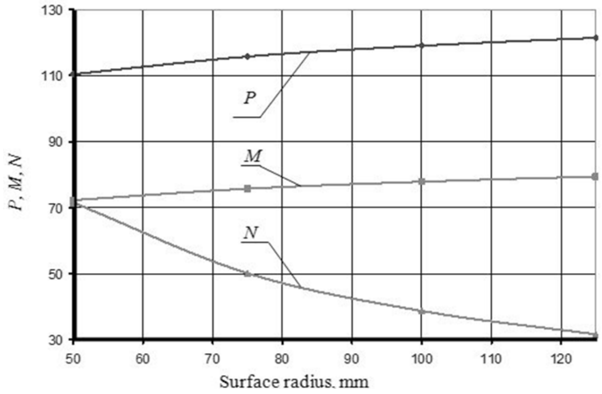

Figure 2. The calculated dependences of integral characteristics of the process on the radius

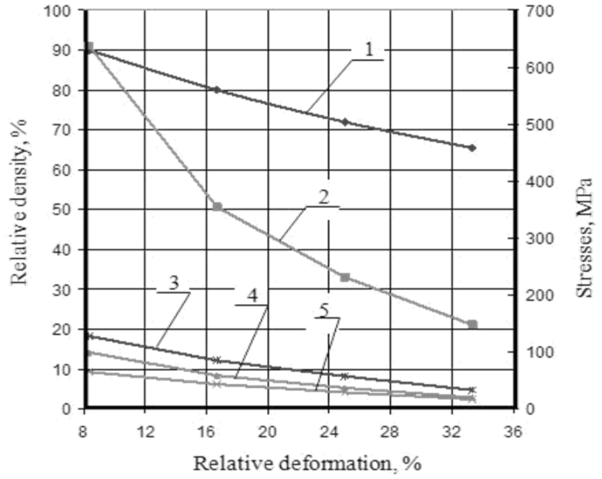

Figure 3. Calculated dependences of integral characteristics for the compression process:

1 – relative density; 2 – P_{max}; 3 – N; 4 – P; 5 – M

Conclusions

Represented calculated dependences can be used to develop optimal technological modes of hybrid restoration process including electrocontact hardening of gas-thermal sprayed powder layer for a given level of physical and mechanical properties of the layer on the frayed surface of the details working under aggressive conditions.

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