Surface Layer Formation When Finish-Hardening Processing of the Parts by Smoothing

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Abstract. Problems of surface layer formation of the parts, when hydraulic smoothing, are considered in this work. The results of theoretical and pilot studies of smoothing in case of nanocarbons and copper salts introduction into the process liquid are given. The influence dependences of the processing modes on roughness and microhardness of surface layer are defined.

1. Introduction

Increasing of operating life of machine parts caused the necessity to develop the new methods of processing and to improve the current ones. One of the promising directions is the usage of hardening processing in combination with different influences (chemical, thermal, ultrasonic and etc.) upon the processed surface, and the development of adaptive influences upon it, including the impacts based on basic research in contact interaction of the materials (Rehbinder and Kirkendall effects, selective transfer effect and etc.). One of the examples of such direction realization when SPD is Papshev’s studies. He showed that microhardness of the processed surface is improved in case of SAS introduction into coolant (Rehbinder effect).

There is a SPD processing of parts where the effort of deformation is provided by the deforming ball, affecting the detail under pressure of process liquid from hydro-power station – hydraulic smoothing (Fig. 1). The advantages of the given method in comparison with the “classic” smoothing are: lower process liquid flow when supply onto the processing zone and constant effort of deformation onto the processed surface.

Studies show that it is possible to influence on the parts precision when hydraulic smoothing by means of parameters control of process liquid (viscosity, pressure). However, there is practically no data concerning the influence of process liquid characteristics when hydraulic smoothing (chemical properties, presence of fillers, viscosity and etc.) upon the quality parameters of surface layer (roughness, microhardness, wear resistance and etc.).
2. Theory

The quality of surface layer when SPD is formed under the process of metal deformation, and the process itself depends on interaction conditions of the instrument and part: metal strain, friction ratio, process modes and etc. It is well-known that the change of process of frictional contact of friction pair can be obtained by introducing friction modifiers into lubricants, such as organic additives, metal and non-metal powders (graphite, molybdenum disulfide, copper and etc.). The introduction of solid friction modifiers into the deformation zone when SPD increases load-carrying capacity of the lubricant, prevents from “dry friction” in case of great loadings. Throughout the process, impregnation of particles-filler onto the contacting surfaces can be observed. So we can suggest that the introduction of solid particles into process liquid when hydraulic smoothing may provide the change of metal deformation process and introduction of particles-filler onto the article surface, and as a result, the improvement of operating characteristics.

The effect of “selective transfer” is well-known from Garkunov’s basic research[1]. This effect allows formation of antifriction coatings on the surfaces of machine parts. The performance of formation the coatings when SPD in case of “classic” supply of coolant is shown in Sorokin’ and Bersudskiy’s studies and other scientists as well. The analysis made the following supposition: when hydraulic smoothing, it is possible to coat thin copper layers onto the surface of parts if copper salts were been introduced into the process liquid[2,3]. This hypothesis is based on copper reducing reaction on the processed surface, where glycerine serves as electron sources for copper irons reduction (Fig. 2).

Liquid between the deforming ball and processed surface when hydraulic smoothing allows realization of the proposed hypotheses[4]. According to contact-hydrodynamic theory of lubricant, the liquid layer thickness between friction surfaces is the following[5,6]:

\[ h = f(\mu_0; \dot{\zeta}; \rho), \]  

where \( \mu_0 \) – liquid viscosity;
\( \dot{\zeta} \) – total angular velocity of the blank and rotating deforming ball;
\( \rho \) – reduced surface radius.
Judging by the fact that liquid viscosity depends on the temperature, filler and pressure ($\mu_\rho = \mu_0 e^{\alpha T}$) then total angular velocity can be defined as follows:

$$\vartheta_\Sigma = \vartheta_{\mu_\rho} + \vartheta_B = \frac{\pi \cdot n}{1000} \cdot (D_{\mu_\rho} + d_B),$$

and reduced radius is:

$$\rho = \frac{D_{\mu_\rho} \cdot d_B}{2 \cdot (D_{\mu_\rho} + d_B)},$$

so we may conclude that liquid layer thickness $h$ depends on such process parameters of mechanical processing by smoothing as process liquid viscosity $\mu$, deformation pressure $P$, processing speed (part rotation frequency) $n$. Thus, factors, affecting the surface layer formation when hydraulic smoothing, can be presented in the form of diagram (Fig. 3).
3. Results and discussion

Pilot studies of hydraulic smoothing on the screw-cutting lathe 16K20F3 type were conducted to confirm the proposed hypotheses. Tested parameters are roughness $Ra$ and microhardness $HV$. Processing parameters are given in Table 1.

Table 1 – Parameters of pilot studies of hydraulic smoothing

| Parameters                  | “Particle impregnation” hypothesis | “Copper film formation” hypothesis |
|-----------------------------|------------------------------------|------------------------------------|
| Filler                      | UDAG-S, Al$_2$O$_3$                | CuSO$_4$*5H$_2$O                   |
| Filler concentration        | 0-1 % mass. 25–30 g/l              |                                    |
| Process liquid              | industrial oil H-40A                | glycerine                          |
| Tool advance, mm/rot        | 0.05 - 0.2                         | 0.05 - 0.2                         |
| Blank rotation speed, m/min | 40 – 165                            | 40 - 165                           |
| Pressure in hydraulics, MPa | 3 – 12                             | 3-5                                |
| Blank material d= 65 mm     | steel 45 State Standard (GOST)1050-88 | steel 45 State Standard (GOST)1050-88 alloy AL-30 |

Pilot studies were conducted with samples made of steel 45 GOST 1050-88 and aluminum alloy AL-30. These materials are widely used in engineering- and automobile industries to manufacture articles and parts operating in friction modes and running in before (shafts, ICE pistons and etc.).

Observed dependences $Ra$ and $HV$, given in Fig. 4 – 9 were obtained when studying the “particle impregnation” hypothesis.

The obtained dependences show that nanocarbons provide formation of the surface with less roughness in case of surface plastic deformation. The increase of particle concentration in operating liquid leads to the decrease of surface roughness. It can be explained by the decrease of pimples amount due to the diamond-carbon particles (UDAG-S) during flowing of liquid with particles relative to the processed surface. Fig. 4 shows that the extreme concentration is not achieved yet. The increase of roughness should be after it, due to the achievement of so called “dry friction” when low amount of liquid component in deformation zone. Distance between the tops of pimples is lengthened when increasing the tool advance due to the reduction of pressure impacts per unit of deformation area. It results to the decrease of plastic deformation caused by less influence of the deforming ball on the pimples. Pressure elevation of operating liquid in hydraulics within the studied range leads to greater metal deformation and less roughness of the processed surface. Blank rotation speed almost has no influence on roughness (Fig. 6).

Introduction of UDAG-S particles into metal deformation zone causes the surface layer to harden much due to the locating of shear stress in thin layer and increasing of normal stress, providing great compression of pimples and metal hardening.
Roughness reduction of processed surface after increasing of tool advance is happened because the degree of loading on to the processed zone is also reduced. Studies showed that blank rotation speed does not influence much on the surface roughness when hydraulic smoothing (Fig. 9). Pressure elevation of operating liquid provides greater plastic deformation of metal and material hardness and, as a result, hardness enhancement of surface layer.

When studying the hypothesis “about copper film formation”, steel samples with copper coating (Fig. 10) no less than 1 μm thickness (Fig. 11) were obtained after processing.
- $V=165 \text{ m/min.}, P=5 \text{ MPa}, C_{NC}=0.6\% \text{ mass.}$
- $S=0.05 \text{ mm/rot}, P=5 \text{ MPa}, C_{NC}=0.6\% \text{ mass.}$

Fig. 8 – Dependence of roughness on tool advance

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- $V=165 \text{ m/min.}, P=5 \text{ MPa}, C_{NC}=0\% \text{ mass.}$
- $S=0.05 \text{ mm/rot}, P=5 \text{ MPa}, C_{NC}=0\% \text{ mass.}$

Fig. 9 – Dependence of roughness on blank rotation speed

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Fig. 10 – Surface of smoothed steel samples

a) without Cu
b) with Cu
4. Conclusion

The results after conducted studies show that process liquid parameters and their control influence much on the formation of surface layer of the processed articles. During theoretical and pilot studies of hydraulic smoothing, the following conclusions were made:

– methodology elements of technological quality assurance of articles when hydraulic smoothing are presented;
– after experimental demonstration of the supposed hypotheses, the possibility to improve quality parameters of the surface by introduction of friction modifiers into the processing zone is shown, as well as the formation of antifriction coatings on the machine parts when hydraulic smoothing;
– influence dependences of processing modes on roughness and microhardness of surface layer is defined, including the introduction of diamond-carbon particles (UDAG-S) into process liquid.

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