JUSTIFICATION OF TECHNOLOGICAL POSSIBILITIES FOR REDUCING SURFACE ROUGHNESS DURING ABRASIVE PROCESSING

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Abstract. The aim of this work is to analytically determine the parameters of surface roughness during abrasive processing and to substantiate the technological possibilities of its reduction in the conditions of transition from the micro-cutting process to the process of elastic-plastic deformation of the processed material. On this basis, the minimum possible values of surface roughness parameters during free abrasive treatment are analytically determined. It is shown that the main way to reduce the surface roughness is to reduce the grain size of the abrasive powder and increase the surface concentration of abrasive grains in the cutting zone. Based on the analysis of the graph of the relative supporting length of the micro-profile of the treated surface experimentally established during abrasive polishing, the significant effect of individual deep scratches on the surface roughness is shown. It is established that they occur as a result of the work of larger grains included in the considered grain fraction with a grain size of 1/0, as well as due to the different heights of the grains in the cutting zone. Therefore, it is recommended to use abrasive grains with a small range of their size spread during abrasive polishing, as well as to use ovalized abrasive grains, which prevent the formation of deep scratches. The obtained results can be effectively used for abrasive polishing of reflective surfaces of space products that operate under light conditions and require high surface roughness.

Keywords: Abrasive Polishing, Micro-Cutting Process, Ovalized Grains.

1 Introduction

The most important condition for the implementation of high-quality mechanical processing of machine parts is to ensure high roughness of the treated surfaces. This is achieved by using effective methods of abrasive processing, including grinding, abrasive polishing and others. Currently, considerable experience has been accumulated in their application. However, as practice shows, it is quite difficult to consistently achieve a significant reduction in the roughness parameter of the treated surface R_a to the level of *0.01* μm (microns) or less, even in conditions of abrasive polishing using an abrasive powder with a grain size of *1/0*. As a rule, certain deep scratches are formed on the processed surfaces, which lead to an increase in the R_a parameter and do not allow to meet the requirements for the quality of processing. This is especially true for the abrasive treatment of reflective surfaces (with very small values of the R_a parameter) of space products that operate at high temperatures (more than 150°C) and lose their performance properties due to significant temperature deformations. As practice shows, for their effective use, it is necessary to provide the roughness parameter of the treated surface R_a at a level of less than *0.05* microns. In this regard, it is important to establish the maximum possibilities for reducing the roughness parameter of the treated surface R_a during abrasive processing and, on this basis, to develop practical recommendations for their technological support, in particular, when processing reflective surfaces of space products.

2 Literature Review

The scientific and technical literature pays much attention to the issues of reducing surface roughness during abrasive processing [1 – 3]. It has been established that high surface roughness can be achieved under free abrasive treatment conditions (especially during abrasive polishing) using fine-grained abrasive powder [4 – 7]. In this case, the processing efficiency is mainly related to ensuring the actual single-layer arrangement of abrasive grains in the cutting zone and excluding their different heights.

The works [8 – 12] show, that it is possible to reduce the surface roughness during abrasive polishing by smoothing the surface layer of the part. This is of great importance for achieving high roughness of the treated surfaces during abrasive polishing and creating optical (reflective) properties on them. In works [13 – 16], the regularities of surface roughness formation during abrasive processing are described analytically from the standpoint of probability theory. This allowed us to theoretically justify the main conditions for its reduction and develop practical recommendations for their technological support. In works [17 – 19], the possibility of reducing the roughness parameter of the treated surface R_a while simultaneously increasing the processing performance and reducing the cutting temperature under deep grinding conditions is shown, which is an important factor improving the efficiency of abrasive processing. At the same time, there are no theoretical solutions in the scientific and

technical literature that allow us to estimate the maximum possibilities of reducing the R_a parameter during abrasive processing. As shown in work [20], they can be achieved under conditions of transition from the micro-cutting process to the process of elastic-plastic deformation of the processed material without chip formation. However, this requires further research to establish the regularities of surface roughness formation during abrasive processing – in the conditions of abrasive polishing.

3 Research Methodology

To solve this problem, it is necessary to set the minimum achievable values of the surface roughness parameter R_a, at which the micro-cutting process stops and the process of elastic-plastic deformation of the processed material begins. This requires an analytical determination of the surface roughness parameter R_a and establishing its relationship with the limit value of the ratio of the cut thickness a_z to the radius of rounding of the abrasive grain R (id. est. the ratio a_z/R), at which there is a transition from the micro-cutting process to the process of elastic-plastic deformation of the processed material. It is also important to establish analytically the relationship between the height parameters of the surface roughness R_a and R_{max} under abrasive polishing conditions. This will allow us to theoretically justify the main ways to reduce surface roughness and make an experimental assessment of the reliability of the results obtained. As an evaluation criterion, it is necessary to use the relative reference length of the micro profile of the treated surface, which is a complex characteristic of the surface roughness parameters. The results obtained will allow us to develop practical recommendations for choosing rational conditions for abrasive processing that provide the lowest values of the surface roughness height parameters.

4 Results

The calculation of the maximum height of the micro-roughness of the treated surface (the surface roughness parameter R_{max}) is based on the calculation scheme of the processing process with abrasive grains of the same size (radius R) with their single-layer arrangement and overlap by the value Δ (Fig. 1).

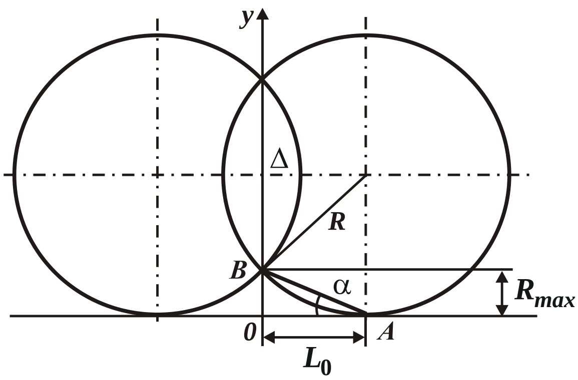

Fig. 1. Calculation scheme of the processing process with abrasive grains of the same size.

In this case, the surface roughness parameter R_{max} is determined by the segment of *OB*. To simplify calculations, the arc of the circle *AB* can be replaced with a straight line *AB* due to the small value of the surface roughness parameter R_{max}.

Fig. 2 shows a graph of changes in the reference length of the micro-profile of the treated surface *L(y)*, formed within half the distance between two adjacent abrasive grains $L_0 = R - \Delta$. The angle α is determined from the ratio: $tg\alpha = R_{max} / L_0$, where $L_0 = \sqrt{R^2 - (R - R_{max})^2} \approx \sqrt{2R \cdot R_{max}}$.

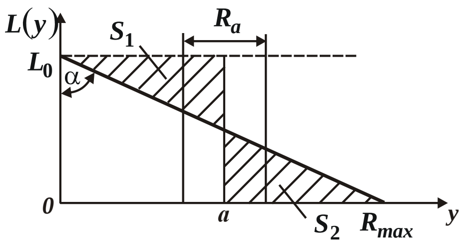

Fig. 2. Graph of changes in the reference length of the micro-profile of the treated surface *L(y)*.

To determine the surface roughness parameter *Ra*, at first set the position $y = a$ of the midline of the micro profile of the treated surface from the condition that the areas S_1 and S_2 are equal (at the Fig. 2 they are shaded):

$$S_1 = \frac{a^2}{2tg\alpha}, \tag{1}$$

$$S_2 = \frac{(R_{max} - a)^2}{2tg\alpha}. \tag{2}$$

Comparing the areas of S_1 and S_2, we get: $a = 0.5 \cdot R_{max}$.

The surface roughness parameter R_a is determined from the condition: $0.5{\cdot}R_a = S_1 / L_0$ (see the Fig. 2). Then $R_a = 0.25{\cdot}R_{max}$.

As you can see, the surface roughness parameter R_a does not depend on the angle α and is 4 times less than the surface roughness parameter R_{max}. Accordingly, the ratio $R_{max} / R_a = 4$, which is consistent with the known experimental data given in the scientific and technical literature [1, 2, 14 – 16], especially when applied to grinding processes.

Obviously, with an increase in the value of Δ (see the Fig. 1), the surface roughness parameters R_a and R_{max} will decrease, and their ratio will remain constant, equal to: $R_{max} / R_a = 4$. The R_{max} parameter can be set from the condition:

$$\left(R - R_{max}\right) = \sqrt{R^2 - L_0^2}\ . \tag{3}$$

Then, after the conversions, it is obtained:

$$R_{max} = \frac{L_0^2}{\left(R + \sqrt{R^2 - L_0^2}\right)}\ . \tag{4}$$

In a generalized form, dependency (4) takes the form:

$$\frac{R_{max}}{R} = \left(\frac{L_0}{R}\right)^2 \cdot \frac{1}{\left[1 + \sqrt{1 - \left(\frac{L_0}{R}\right)^2}\right]}\ . \tag{5}$$

Table 1. The calculated values of the R_{max}/R ratio.

L_0/R	0.000	0.200	0,400	0.600	0.800	1.000
R_{max}/R	0.000	0.020	0.083	0.200	0.400	1.000

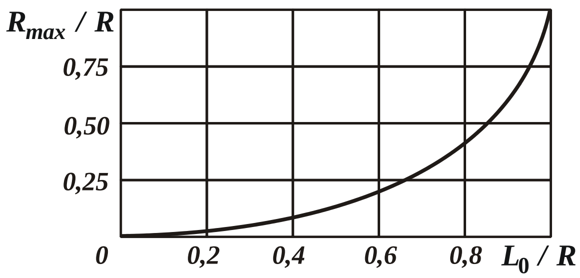

Fig. 3. The dependence of the ratio R_{max}/R from the ratio L_0/R.

As follows from dependency (5), Tabl. 1 and Fig. 3, with a decrease in the L_0/R ratio, the R_{max}/R ratio decreases approximately in a parabolic relationship, i.e. quite intensively. Therefore, the main condition for reducing the parameter R_{max} should be

considered a decrease in the parameter L_0 by increasing the number of simultaneously working abrasive grains with their single-layer arrangement (see the Fig. 1), as well as by reducing the radius of the abrasive grain R. Due to this, the value $L_0 \rightarrow 0$ and, accordingly, $R_{max} \rightarrow 0$.

The surface roughness parameter R_{max} in the limit takes a value equal to the thickness of the cut with a separate abrasive grain (see the Fig. 1). Accordingly, the a_z/R ratio is analytically described by the dependence (5). According to the experimental data of professor I. Kragelsky, given in [20], the micro-cutting process is feasible under the condition $a_z/R = 0.14 \ldots 0.17$. At lower values of the a_z/R ratio, only elastic-plastic deformation of the processed material occurs without the formation of micro-arrays. Therefore, the lowest values of the R_{max} parameter can be achieved in the conditions of transition from the micro-cutting process to the process of elastic-plastic deformation of the processed material. Based on the conditions $R_{max}/R = 0.17$ and $R_{max}/R_a = 4$, we have: $R_a = 0.0425 \cdot R$. If we take $R = 0.5$ microns (for a grain size of $1/0$), then $R_a = 0.021$ microns.

If $a_z/R = 0.17$, the limit value of the ratio L_0/R, according to dependence (5), is 0.185. Therefore, 5.4 times more abrasive grains should be involved in the micro-cutting process at the same time than in the case of $L_0/R = 1.0$. From this, you can set the required number of abrasive grains located on the unit area of the working part of the abrasive tool, which will provide processing with the specified values $a_z = R_{max}$ and $R_a = 0.25 \cdot R_{max}$.

Given the expression $L_0 = R - \Delta$, we have: $L_0/R = 1 - \Delta/R$, from which the ratio is determined:

$$\frac{\Delta}{R} = 1 - \frac{L_0}{R} = 0{,}815 . \qquad (6)$$

According to the experimental data of Professor N. Bogomolov, given in [20], the limit values of a_z/R, at which the micro-cutting process is carried out, vary within $0.04 \ldots 0.08$. In this case, the surface roughness parameter R_{max} can take even lower limit values: $R_{max} = (0.04 \ldots 0.08) \cdot R$. Accordingly, the surface roughness parameter $R_a = (0.01 \ldots 0.02) \cdot R$. If we take $R = 0.5$ microns (for a grain size of $1/0$), then $R_a = 0.005 \ldots 0.01$ microns. To meet this condition, an even greater number of abrasive grains must participate in the micro-cutting process than in the previous case, established by professor I. Kragelsky this is achieved by increasing the surface concentration of grains or reducing the processing performance (for example, by reducing the pressure in the processing zone during abrasive polishing).

At the Fig. 4 [21] shows experimentally established graphs of changes in the relative reference length of the micro-profile of the treated surface t_p of samples made of AMr4 alloy after their processing by various methods, including after abrasive polishing with ACM $1/0$ paste (i.e. with a grain size of $1/0$). Processing mode: the circumferential speed of the polisher is 50 m/s; the specific pressure is 500 kPa.

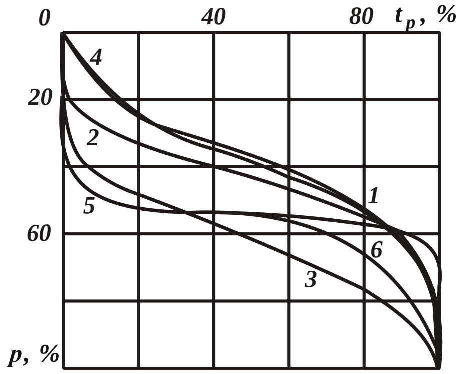

Fig. 4. Relative reference lengths of the micro profile of the treated surface of samples made of AMr4 alloy after different processing methods: *1* – rolled (initial surface); *2* – waterjet processing; *3* – fine turning; *4* – milling; *5* – abrasive polishing; *6* – diamond turning.

The Fig. 5 schematically shows a simplified view of this graph obtained after abrasive polishing, where $\overline{L}(y)$ = $L(y)/L_0$ is the relative reference length of the micro – profile of the treated surface; L_0 is the base length of the micro profile of the treated surface, mm.it should be noted that AMr4 alloy is used for manufacturing products with reflective surfaces for space purposes.

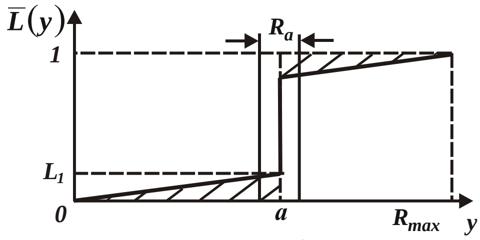

Fig. 5. The type of simplified function *L(y)*.

From the Fig. 5 it follows t_p that the function initially increases slightly along the *0y* axis, and then when the $y = a$ position is reached (i.e., the midline of the micro profile of the treated surface), it increases intensively at an angle close to 90° to the *0y* axis. In the final section, the function t_p under consideration asymptotically tends to a single value. Obviously, the surface roughness parameter R_a in this case is determined by the initial and final sections of the function t_p (at the Fig. 5 they are shaded). Then from the condition $0.5 \cdot R_a = 0.5\ R_{max} \cdot L_1$ we have:

$$\frac{R_{max}}{R_a} = \frac{1}{L_1}, \tag{7}$$

where L_1 is a dimensionless quantity ($L_1 << 1$)

As you can see, the ratio R_{max}/R_a in this case is much greater than one. This is confirmed by experimental data [21], according to which the ratio $R_{max}/R_a = 30.3$; $R_a = 0.1$ microns; $R_{max} = 3.03$ microns. Accordingly, the dimensionless value $L_1 = 0.033$, i.e. $L_1 << 1$. This type of change in the R_{max}/R_a ratio is due, firstly, to the presence of individual deep scratches on the treated surface, which are formed by larger grains that are part of the grain fraction. Second, the location of the abrasive grains at different heights. This is also consistent with the research results reported in works [22, 23].

Therefore, the spread of grain sizes and their different heights in the cutting zone is associated with the presence on the graph (see the Fig. 5) of two sufficiently extended sections characterized by a slight change in the function $\overline{L}(y)$ along the $0y$ axis. Obviously, by reducing the number of larger grains in the total mass of grains involved in the micro-cutting process, you can significantly reduce the initial and final sections of the function $\overline{L}(y)$ in the Fig. 5. Ideally, the function $\overline{L}(y)$ takes the form of a straight line that actually coincides with the position of the middle line $y = a$. In this case, the ratio $R_{max}/R_a = 4$ (according to the Fig. 2), and the surface roughness parameter $R_a \rightarrow 0$.

Thus, it is theoretically and experimentally established that during abrasive polishing, the surface roughness parameter R_a can be reduced to the lowest possible value by: 1) reducing the range of variation in the size of the grain fraction used for processing; 2) ensuring the transition from the micro-cutting process to the process of elastic-plastic deformation of the processed material. In this regard, an important condition for reducing the R_a parameter should be considered the use of oval-shaped abrasive grains that exclude the formation of deep scratches on the treated surfaces. In the course of experimental studies of abrasive polishing with the use of ovalized abrasive grains (*1/0* grain size), it was found that the surface roughness parameter R_a decreases to a value of *0.01* microns. This is quite consistent with the above theoretical data for the considered case $a_z/R = 0.04 ... 0.08$ (according to the experimental data of professor N. Bogomolov) as a result, as established experimentally, the light-reflecting properties of the treated surface of samples made of AMr4 alloy are provided, due to high surface roughness.

5 Conclusions

The paper presents analytical dependences for determining the parameters of surface roughness during abrasive processing. It is shown that when processing with a free abrasive, the main conditions for reducing surface roughness are: reducing the grain size of the abrasive and increasing the surface concentration of grains in the cutting zone. It is established that the lowest values of the height parameters of the surface roughness during abrasive polishing are achieved under the condition of transition from the micro-cutting process to the process of elastic-plastic deformation of the processed material. This is confirmed by the results of experimental studies of the relative reference length of the micro-profile of the treated surface of samples made of

AMr4 alloy after their processing by abrasive polishing with ACM *1/0* paste. It was found that the roughness of the treated surface mainly depends on the presence of individual deep scratches on it-scratches formed as a result of the work of larger grains present in the bulk of the grains, as well as the different heights of the grains in the cutting zone. Therefore, to eliminate them, it is necessary to reduce the range of grain size spread used for processing, and use abrasive grains of ovalized shape. The results of the research are recommended for use in abrasive polishing of reflective surfaces of space products that reduce the light effect and the probability of temperature deformations of products by reducing the surface roughness.

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