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Generation of Surface Energy in Metals Using Row-by-Row Microdeformation

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Abstract

An experimental study was carried out concerning the change in surface energy of structural materials exposed to row-by-row microdeformation after machining by milling operations. The study simulated the impact produced on the surface by rigid prismatic parts having resilient material recovery after the passing of the tool. The influence of microdeformation modes on the surface energy at different values of the elastic recovery in the range from several micrometer fractions to 4 microns was examined. The change in the surface roughness as a result of microdeformation of the planes by the end mills in parallel with the change in the value of the generated surface energy was analysed. The dependencies of the surface energy accumulated as a result of milling and microdeformation on the depth and speed of its longitudinal feeding were obtained. The Abbott-Firestone curves (material ratio curve of the profile) were drawn. The materials of this article may be useful for the development of a technology providing high performance characteristics of products before welding, soldering, gluing, applying protective coatings, etc. during production, operation and repair.

Keywords: surface energy, cutting modes, performance properties, roughness, microdeformation, milling.

INTRODUCTION

The never-ceasing growth of technical requirements to engineering products and instrumentation makes it necessary to improve the existing technologies and to develop new ones in order to meet these requirements.

The performance properties of machine parts are influenced by the energy state of their surface layer [1-3]. This effect comes out when applying protective coatings, gluing, soldering, welding and performing other technological operations.

According to the electronic theory of the surface energy of metals [4-6], the amount of surface energy depends on the forces of interatomic interaction, generated by the technological impact upon manufacturing surfaces. The electronic work function can be considered as a basic parameter of a solid body [7-12].

When shaping surfaces by machining (when the material is consistently separated from the initial workpiece), the trajectory of the cutting tool is a set of successive geometric positions (Fig. 1).

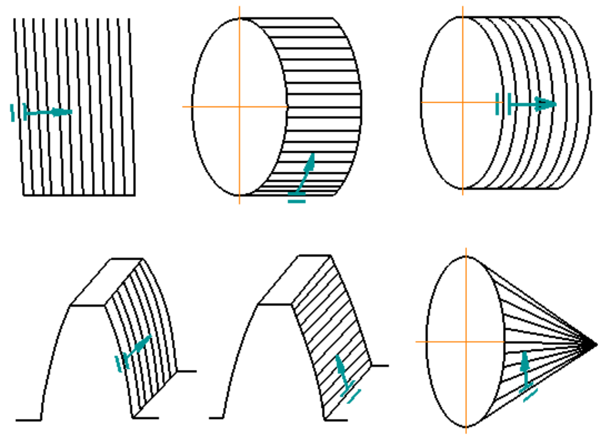


Figure 1: Patterns for the formation of surfaces of the parts by cutting

The analysis of the patterns shows the row-by-row nature of the traces from the tool remaining on the surface formed by cutting. The frequency of the rows is assigned depending on the requirements to accuracy and quality of the surface obtained, physical and mechanical properties of the workpiece and tool materials, and the rigidity of the technological system, and is expressed through the "tool feeding". The main technological processing parameters are: the machining method, the geometry and material of the cutting part of the tool, and the cutting modes, such as the cutting depth (the amount of the layer cut in one working movement of the tool), the cutting speed (speed of the tool moving along the lines), the tool feeding (the distance between the rows). The depth of the layer cut in one working movement of the tool h (Figure 2) should be greater than the blunting radius of the cutting edge of the tool ρ, the minimum value of which, as practice shows, is 25-50 μm. Otherwise, material separation (cutting) does not take place, and the surface undergoes elastoplastic deformation. Therefore, as a rule, the cutting depth is never assigned less than 25 μm when machining with a blade tool.

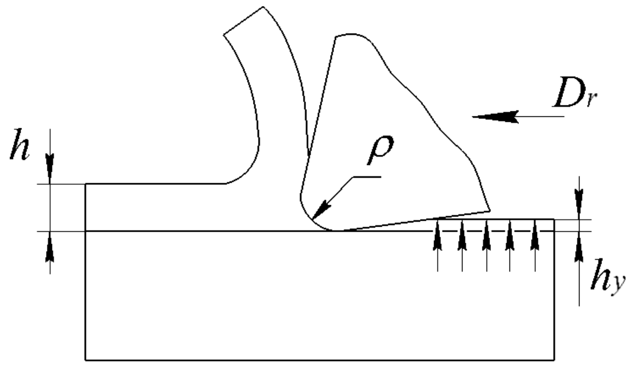


Figure 2: The diagram for removing a layer of the material when machining with a blade tool

The material of the part at the point of contact with the tool is compressed under the impact of the tool, and then elastically restored (when the tool is retracted) by the amount of elastic recovery h_y (Figure 2), the value of which is 1 ... 5 µm, and even more, depending on the properties of the material of the workpiece and the rigidity of its structure. The elastic recovery value may be quite enough to create an impact on the surface when the tool passes the same row path again (surface profile - Fig.3).

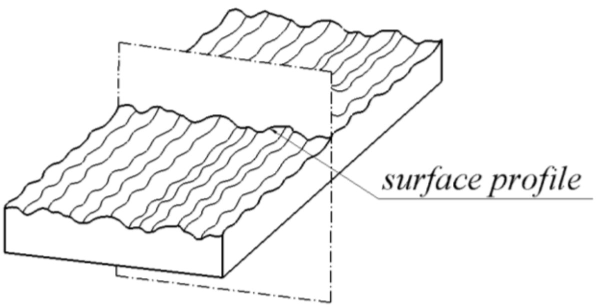


Figure 3: Surface profile

Such impact will lead to microdeformation of the surface layer, local compression and distortion of the crystal lattice, breakdown of parts of the lattice and individual atoms by frictional forces (Figure 4), a change in the microgeometry of the surface, which will produce a change in the physical and mechanical properties of the boundary layer of the processed material.

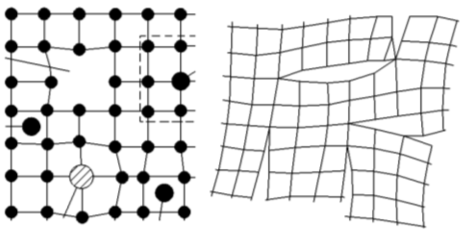


Figure 4: Distortion of crystal lattices

The study by [11-12] shows a significant influence of technological parameters on the value of surface energy during surface processing by milling.

Determination of the parameters of technological impact, providing the required physical and mechanical properties of surfaces, is an urgent task.

MATERIALS AND METHODS

The objective of this work was an experimental study concerning the change in surface energy of a material exposed to row-by-row microdeformation after cutting. The work simulated impact on the surface of parts such as rigid casings, the design of which does not undergo elastic deformations when cutting, but features elastic recovery of the material after the passing of the tool. Material of the parts – C45. Material of the tool (cutting edge) – GC1040. The blunting radius of the cutting edge of the tool ρ= 0.02 mm. The experiments were performed on a vertical milling machining centre with a MiniMill 450 CNC machine. At the same time, the values of surface energy and the parameters of microgeometry were recorded during cutting and the subsequent row-by-row microdeformation. The value of surface energy was determined by the method of a static capacitor using a device in accordance with the structural scheme of A.Yu. Albagachiev, the surface microgeometry parameters – using ABRIS-PM7 profilograph-profilometer.

The influence of microdeformation modes on the surface energy at different values of the elastic recovery was examined h_y with regard to:

- materials of rigid structures – the value of h_y less than 1 µm;
- materials of the structures prone to elastic recovery after shaping by cutting – $h_y \approx 2$ µm and $h_y \approx 4$ µm.

During the experiments, the surface was exposed to milling with the depth t = 0.5 mm (finishing). Cutting speed V_c = 40.19 m/min, longitudinal feeding of the cutter by one tooth S_z=0.04 mm/tooth. After processing the materials of rigid structures ($h_y \approx 0$ µm), the average value of surface energy was E_n=2371,156 mJ/m^2, and the mean absolute error of the surface profile was Ra=4.724 µm. Then the surface was exposed to row-by-row microdeformation with the same tool.

The surface energy value after the first passing of the microdeformation was E_n =2377,732 mJ/m^2, and after the second passing – E_n =2383,909 mJ/m^2. The subsequent microdeformation passings did not lead to significant changes in the value of surface energy. Similarly, we conducted an experimental study of milling surfaces at depths h=0.3 mm and h=0.1 mm. The average surface energy value after milling at depth h=0.3 mm was E_n=2347,244 mJ/m^2, and the mean absolute error of the surface profile was Ra=4.409 µm. The surface energy value after the first passing of microdeformation was E_n =2363,385 mJ/m^2, and after the second passing E_n =2368,964 mJ/m^2. The subsequent microdeformation passings did not demonstrate significant changes in the value of surface energy.

International Journal of Applied Engineering Research ISSN 0973-4562 Volume 12, Number 24 (2017) pp. 15621-15626

RESULTS

The average surface energy value after milling at depth h=0.1 mm was E_n=2362,587 mJ/m^2, and the mean absolute error of the surface profile was Ra=4.516 μm. The surface energy value after the first passing of microdeformation was E_n =2368,167 mJ/m^2, and after the second passing E_n=2373,946 mJ/m^2.

The graphs of surface energy changes after milling and microdeformation are shown in Fig. 5. The subsequent passings (number 3 through 10) did not bring any changes in the value of surface energy.

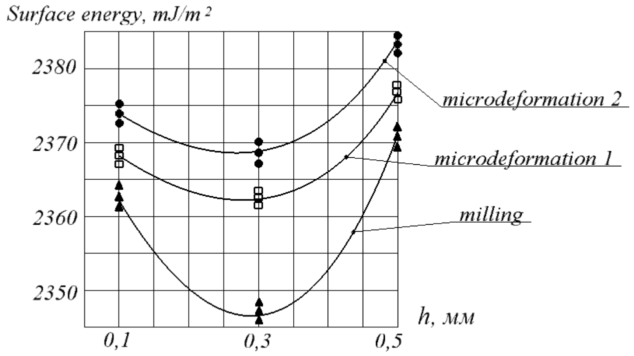


Figure 5: Change in surface energy after cutting and microdeformation

The performed studies showed that in order to increase the accumulated energy, additional microdeformation passings shall be recommended after milling. The optimal number of microdeformation passings is two, since the subsequent passings have practically no effect on the surface energy value. In addition, the results of surface energy measurements have shown that microdeformation is most effective after milling to a depth of h=0.3 mm.

DISCUSSION AND CONCLUSION

The analysis of the graphs in Fig. 5 shows that the lowest surface energy value accumulates after milling to a depth of h = 0.3 mm, and when milling to a depth of h=0.5 mm, the surface energy value has the greatest value. The high level of surface energy during milling to a depth of h = 0.1 mm is explained by the fact that at a small depth the share of elastic deformations of the structural material in the total volume of deformation is high, and the plastic deformation does not achieve values leading to microcracking of the material. The further increase in the depth of milling to h=0.3 mm causes a large plastic deformation which forms microcracks leading to the release of the accumulated energy [7]. The further increase in depth causes the greatest plastic deformation of the surface, leading to cold hardening with the accumulation of the greatest level of surface energy. The surface energy graphs after microdeformation show an increase in surface energy in all cases of preliminary milling. This is due to the fact that during microdeformation there is a crushing (plastic deformation) of the surface microroughness vertices, which leads to accumulation of surface energy.

Profilograms of surface roughness after milling and microdeformation with feeding S_z =0.04 mm/tooth are presented in Figure 6.

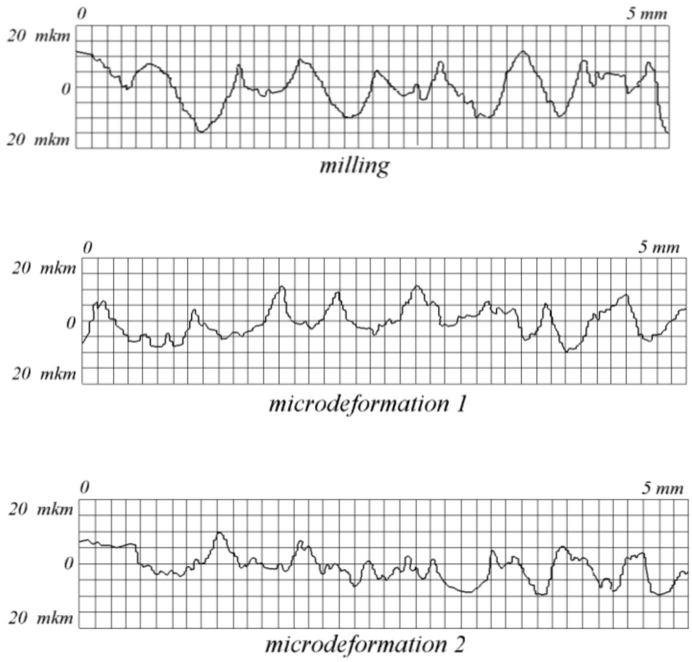


Figure 6: Surface profilograms

The mean absolute error of the surface profile decreased by 11.36% from Ra=4.724 μm to Ra=4.187 μm. Note the change in the Abbott-Firestone curve presented in Fig. 7 (P= $f(T_P)$ graphs) [8]. It characterizes the profile collapse rate as a function from the P level (the profile section level expressed as a percentage of the protrusion line up to the profilogram cavity line within the basic length equal to the surface evaluation length). The profile collapse rate is the ratio of the length of the material of profile elements at a given level P to the evaluation length.

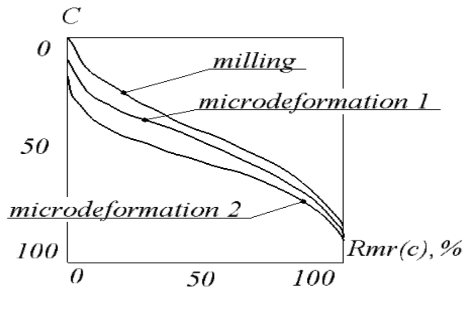


Figure 7: The Abbott-Firestone curves of the surface profile

Figure 8 shows the graphs of changes in the average height of microroughness of surfaces after milling and microdeformation.

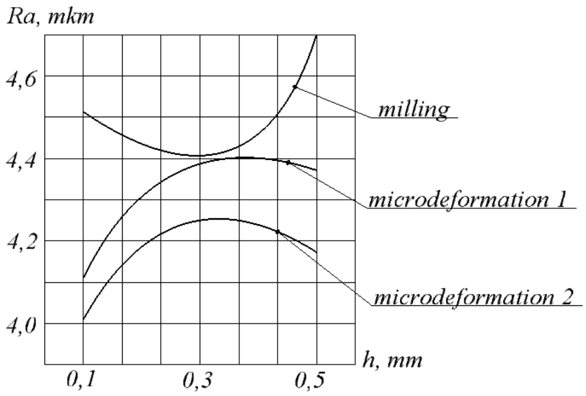


Figure 8: Graphs of changes in the average height of surface microroughness after milling and microdeformation

The graph of the average height of the surface microroughness, corresponding to milling, has a nature similar to the surface energy graph when milling (Fig. 7). The greatest influence of surface microdeformation after milling to a depth of h=0.3 mm is similar to the nature of the graph of the average height of surface microroughness after microdeformation (Fig. 8). This circumstance is similar to the conclusions drawn in work [9] on correlation of surface energy and the average height of microroughness.

At the same time, the task was to examine the effect of the frequency of rows (longitudinal feeding) on the change in surface energy. That is why the feeding S_z during microdeformation by a milling cutter was changed in the range of ± 30%. The graph of the dependence of surface energy on feeding by a tooth during microdeformation after preliminary milling to depths h=0.5 mm, h=0.3 mm and h=0.1 mm is shown in Fig.9.

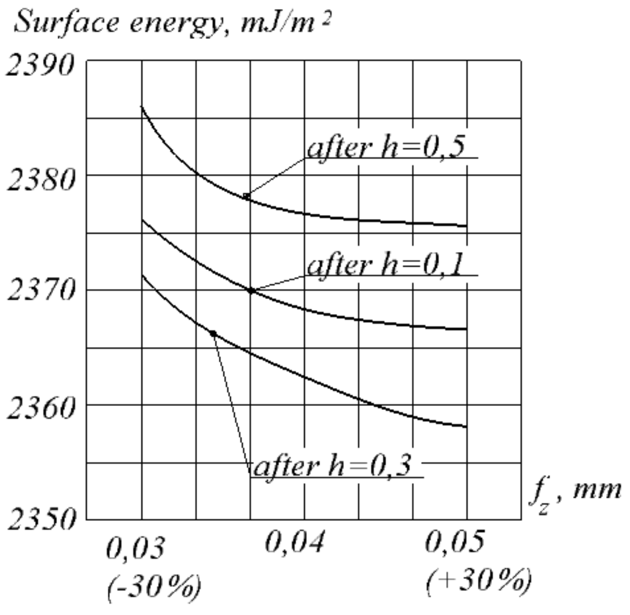


Figure 9: Dependence of surface energy on feeding by a tooth

Analysing the graphs, we can conclude that as the feeding S_z is increased during microdeformation by a milling cutter, the surface energy value decreases. The decrease in the surface energy value as the feeding rate is increased during cutting was established in studies [5, 6, 10]. The experiment carried out within the framework of this study showed the same pattern during microdeformation. The lowest surface energy value accumulates after milling to a depth of h=0.3 mm, and the greatest surface energy value – after milling to a depth of h=0.5 mm. This shows the convergence with the results obtained in the first stage of the experiments.

In the third stage of the research, the influence of microdeformation parameters on the surface energy value was determined. The surface energy resulting from the change in the value of elastic recovery after shaping by cutting ($h_y \approx 2$ μm and $h_y \approx 4$ μm) was measured. The results of the experiments with microdeformation of the surface after preliminary milling to a depth h=0.3 mm are shown in Fig. 10.

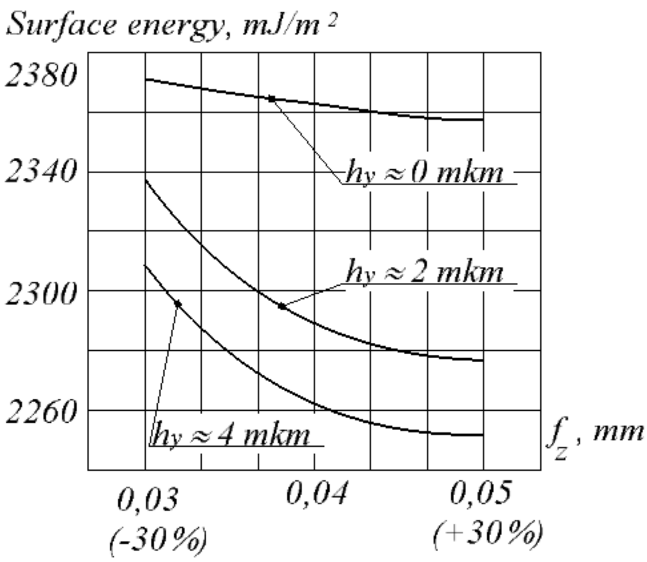
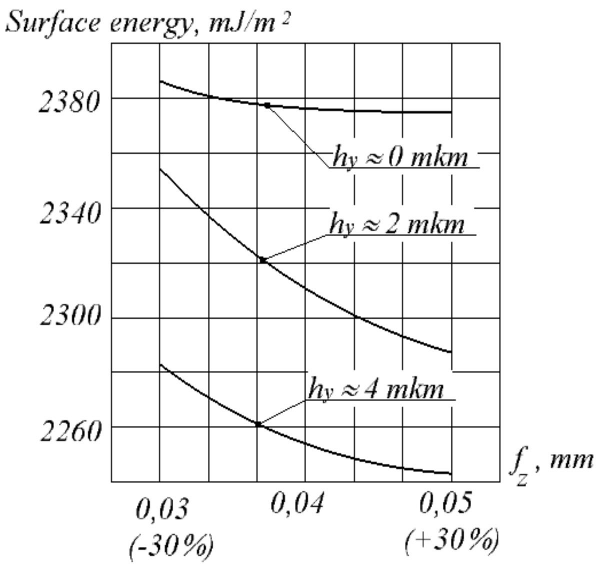


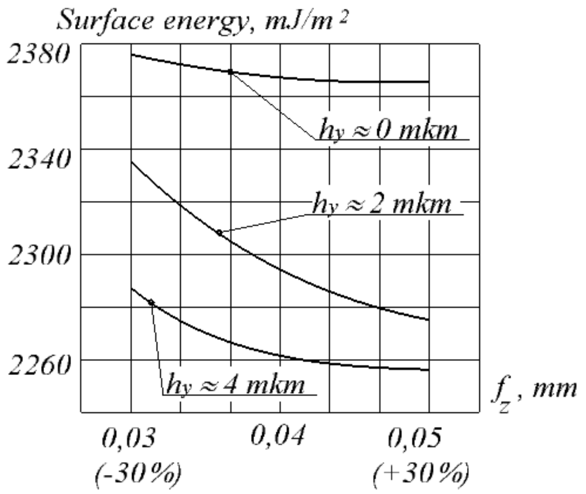
Figure 10: Dependence of surface energy on feeding by a tooth during microdeformation to a depth of 2 μm and 4 μm (after h=0.3 mm)

The analysis of the results revealed that as the depth of microdeformation h_y increases, the value of surface energy decreases. This is due to the smoothing of the microrelief vertices of the surface accompanied by unloading of the energy concentrator zones. Similar results were obtained during microdeformation of the surface after preliminary milling to depths h=0.5 mm (Fig. 11, a) and h=0.1 mm (Fig.11, b).

International Journal of Applied Engineering Research ISSN 0973-4562 Volume 12, Number 24 (2017) pp. 15621-15626



(a)



(b)

Figure 11: Dependence of surface energy on feeding by a tooth during microdeformation to a depth of 2 μm and 4 μm (after h=0.5 mm and h=0.1 mm)

Also, a comparative analysis of the mean absolute error of the profile and the curves of the profile collapse rate was performed within the evaluation length after milling and microdeformation. The surface profilogram during feeding S_z=0.04 mm/tooth is presented in Fig.12.

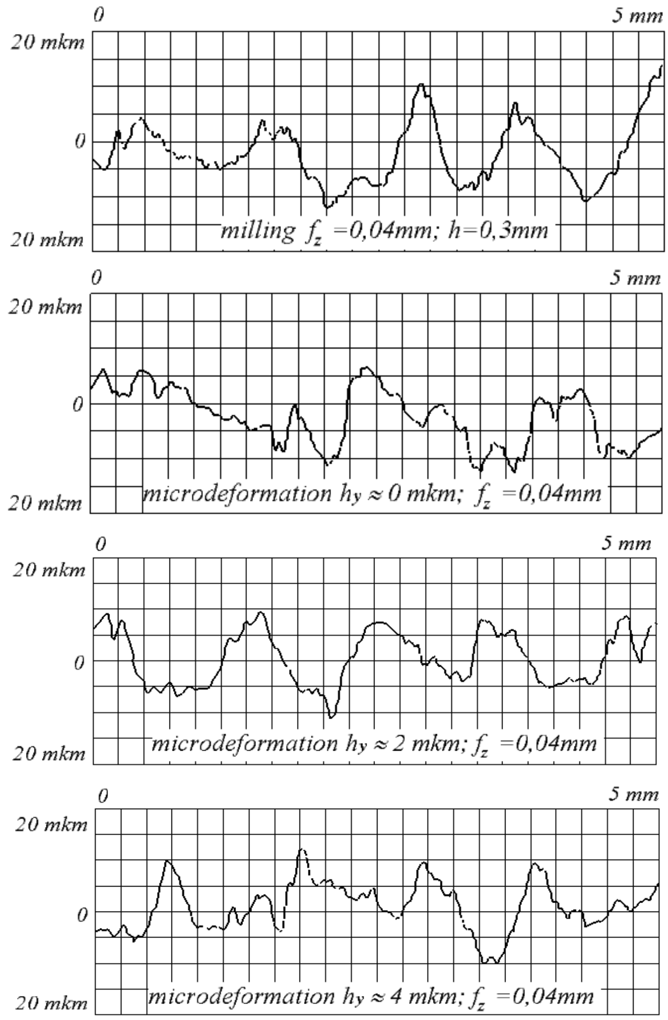


Figure 12: Surface profilogram after milling and microdeformation

The deformation of the height combs of the irregularities is mostly observed during microdeformation of the surface of rigid structures ($h_y \approx 0$ μm).

The profile collapse rate curve during feeding S_z =0.04 mm/tooth is presented in Fig.13.

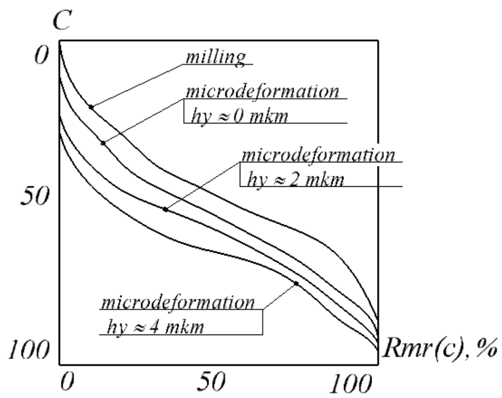


Figure 13: Profile collapse rate curve

The analysis of the results revealed that with an increase in the value of the elastic recovery of the material (the depth of microdeformation), the profile collapse rate decreases.

CONCLUSIONS

1. In order to increase the accumulated energy, additional microdeformation passings shall be recommended after shaping by cutting. The optimal number of microdeformation passings is two.
2. With regard to materials of rigid structures that are not prone to elastic recovery, the results of surface energy measurements have shown that microdeformation is most effective as a subsequent stage after milling to a depth of h=0.3 mm. The lowest surface energy value accumulates after milling to a depth of h=0.3 mm, and when milling to a depth of h=0.5 mm, the surface energy value has the greatest value.
3. It was also concluded that with an increase in the feeding rate Sz during microdeformation of materials of rigid structures and materials of structures prone to elastic recovery by a milling cutter, the surface energy value decreases. The lowest surface energy value accumulates after milling to a depth of h=0.3 mm, and the greatest surface energy value – after milling to a depth of h=0.5 mm.
4. For materials of structures prone to elastic recovery after shaping by cutting, the results of measurements have shown that as the depth of microdeformation increases, the surface energy value decreases.
5. The comparative analysis of the mean absolute error of the profile after milling and microdeformation revealed that cutting and plastic deformation of the height combs of the irregularities are observed mostly during microdeformation of the surface of rigid structures. The analysis of the profile collapse rate curves revealed that with an increase in the value of the elastic recovery of the material (the depth of microdeformation), the profile collapse rate decreases.

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