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RESEARCH

Effects of Machining Regime on Tribological Properties of Machined Surfaces

This paper presents the results of tribometric investigations of ground surfaces machined with different combinations of grinding regime. Though they belong to the same class of surface roughness, they show significant differences in tribological properties.

This is a consequence of differences in the state of material in the surface layers, which arise from the machining regime parameters variation. These results emphasize the essential importance of correct definition of tribological criteria for contact surface states in the design phase.

Keywords: *Tribological properies, ground surfaces, roughness, microhardeness, friction, wear*

1. INTRODUCTION

In engineering practice, in choosing the types and orders of technological operations of triboelement machining, basic attention is paid to attaining the geometrical accuracy and contact surface roughness set by the design. Technical conditions defined in such a way can, in principle, be satisfied by different types of final machining, as well as by different conditions of their realization. However, investigations show that triboelements obtained this way can demonstrate significant differences in their tribological characteristics [1, 2, 3].

To understand this phenomenon it is necessary to keep in mind that the character and intensity of tribological properties in tribomechanical systems are caused by the quality of the contact surfaces. In that, the contact surfaces quality has to be accepted as a complex of parameters of the surface micro geometry, and parameters of the physical - mechanical states of materials in the thin surface layers. Thus understood quality of contact surface is directly caused by the type and conditions of the machining technological operations realization.

By technical conditions the roughness class is most frequently defined only by the height parameters of the micro geometry. Other tribologically relevant characteristics of micro geometry remain out of reach of technical requirements. Also, by technical conditions are not enhanced other, very important indicators of the surface quality, like the micro hardness of the surface layer, its structure, residual stresses, etc.

In this paper results are presented of tribometric investigations of ground surfaces from different conditions of planar grinding. Though they belong to the same class of roughness, they are characterized by large differences in wear resistance. This, of course, suggests the necessity of extending the list of technical requirements of contact surfaces.

2. EXPERIMENTAL DETAILS

2.1. Test system and samples

Investigation of tribological properties of ground surfaces was done on the universal tribometer TR-3 [1] with the pin on disc system under conditions of boundary lubrication (Fig. 1). The cylindrical pin with flat ends is pressed against the cylinder wall of rotating steel disk. This provided a nominal line contact Hertzian geometry for the contact pairs.

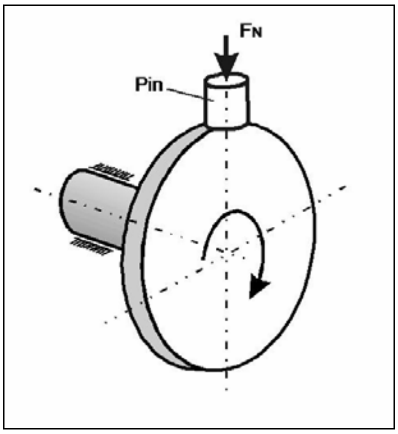

Figure 1. Contact geometry

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The test pins were cylinders of 10 mm diameter made of steel C.5432 (0.3C, 2.0Cr, 2.0Ni, 0.4Mo) in the hardened and tempered, with hardness 48 RC. Contact surfaces of the pins were machined by planar grinding with the 2B60K6V33 grinding wheel of dimensions 250 x 32 x 30 with complete variation of three grinding depths ($\delta_1 = 0.005$ mm, $\delta_2 = 0.02$ mm, $\delta_3 = 0.06$ mm), and three feed speeds of workpieces (v_{r1}= 1.5 m/ min, v_{r2}= 8.0 m/ min, v_{r3}= 15 m/ min).

Case-hardened chromium-nickel steel C.5420 disks (8 mm thickness, 68 mm diameter, 60 HRC hardness) were used as the movable contact pairs during all tests. All the disks were machined at the same conditions. The roughness of the contact surfaces was Ra = 0.2 μm.

Investigation of the tribological behavior of the ground surfaces was done under the following conditions: normal loading 8 daN, sliding velocity 1.0 m/s, contact duration time 90 min.

3. ROUGHNESS AND MICROHARDNESS OF GROUND SURFACES

The contact surfaces that were obtained by the given grinding conditions were investigated in terms of microgeometry and microhardness. If the obtained results are analyzed from the aspect of parameters R_a and R_{tm} (Table 1), which represent criterion for definition of the roughness classes (according to JUS M.A1.021), one can come up with the conclusion that all the specimens have contact surfaces in the limits of the N5 quality (R_a = 0.2 - 0.4 μm, R_{tm} = 0.8 - 1.6 μm). However, though they are within the same roughness class, surfaces machined by different combinations of the grinding regime parameters have different structural characteristics of roughness.

This is especially obviously expressed in existence of very different forms of the bearing curves, i.e., diagrams of the roughness profile amplitudes distribution. Namely, depending on the grinding regime surfaces are formed to which corresponds the normal distribution law of amplitudes (R_{sk} has approximately the value equal to 0), and also the surfaces with more or less expressed asymmetry of the distribution law. The general conclusion can be drawn that the normal distribution of amplitudes is realized for larger cutting depths, whereas to the smallest depth (0.005 mm) correspond asymmetric distributions - in positive and negative sense, depending on the relative motion in the machining by grinding.

Table 1. Roughness of ground surfaces

δ, mm	0.005			0.02			0.06		
V_r, m/min	1.5	8	15	1.5	8	15	1.5	8	15
R_a(mm)	0.20	0.25	0.32	0.28	0.22	0.35	0.29	0.24	0.35
R_{tm}	1.50	1.98	2.04	2.06	1.55	2.27	1.90	1.78	2.32

The most obvious differences are in the bearing curves that correspond to surfaces machined with the smallest grinding depth (0.005 mm), what is shown in Figs. 2 - 4. These differences are a consequence of the specific kinematics of the process of micro cutting that are caused by the small grinding depth and different feed speeds v_r.

At the smallest velocity v_r, multiple overlapping occurs of parts of the trajectories of individual abrasive elements of the grinding tool In the machined surface, this causes t_p= 50 % to be realized at just 30 % of the relative roughness profile. Higher velocities v_r prevent this type of micro cutting, which causes a very inconvenient distribution of material with roughness depth.

The results of microhardness measurement have indicated that some relaxation of the material took place in the surface layers. It is expressed as the rate of microhardness change at the depth of 0,01 mm in Fig. 5. It can be seen that decrease of the microhardness corresponds to smaller feed speeds of the workpiece and higher grinding depth.

The obtained grinding effects are determined by the influence of the tested grinding parameters on the thermal regime of machining. Higher grinding depths, through simultaneous increase in the power of the heat source and in the time of its acting on the machined surface cause increases in the thermal loading of surface layers material, giving rise to structural changes. A change in the feed speed, on the other hand, does not display some effects on the thermal source power and the time of his action. Higher feed speeds mean a more powerful heat source, bat also a shorter time of exposure of machined surfaces to thermal influence that is of crucial influence to the quantity of heat entering the workplace.

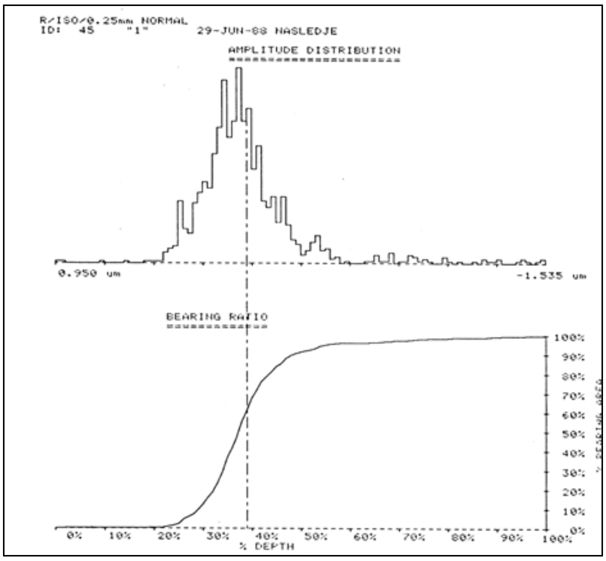

Figure 2. Amplitude distribution and bearing curve for δ=0.005 mm and vr=1.5 m/min

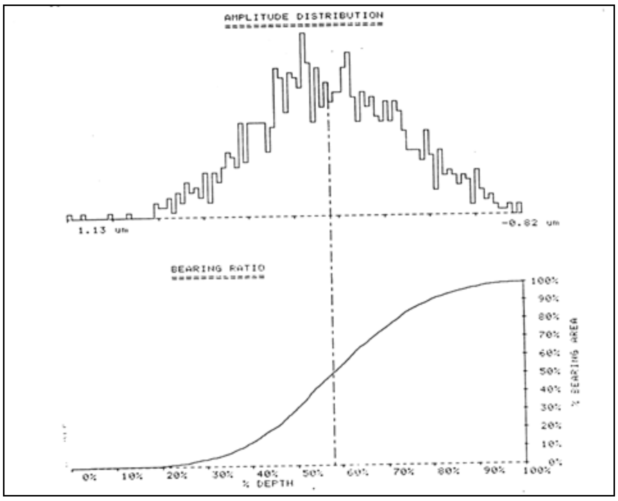

Figure 3. Amplitude distribution and bearing curve for δ=0.005 mm and vr= 8 m/min

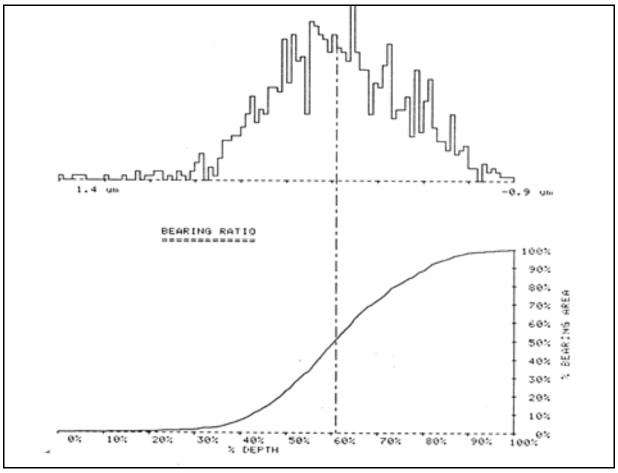

Figure 4. Amplitude distribution and bearing curve for δ=0.005 mm and vr=15 m/min

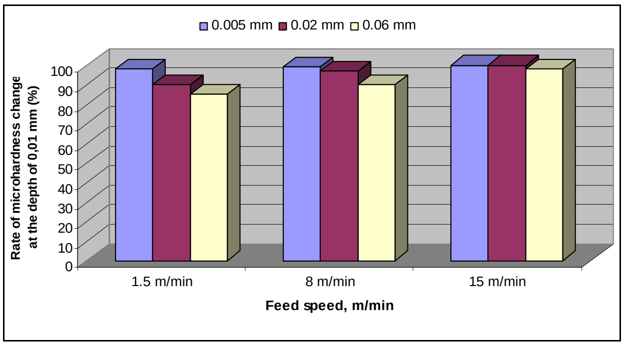

Figure 5. Microhardness change versus parameters of grinding

4. FRICTION AND WEAR OF GROUND SURFACES

The computed friction coefficient signals were obtained automatically during all tests by means of the data acquisition software. The dependence of the friction coefficient upon the parameters of grinding conditions for tested contact surfaces is presented in Fig 6. The experimental values on the diagram represent averages for all obtained time series with 10 repetitions. It can be seen that the distribution of the friction coefficients values is within relatively narrow limits of 0.88 - 0.1. Somewhat more prominent differences can be expressed only during the running in period, which is happening during relatively short time in contact with the disk surface made of material with significantly higher hardness.

By measurements of wear, significant differences were seen in the wear resistance for the tested specimens obtained from different combinations of grinding regime parameters. The medium values of the measurements of the wear scars widths on the pin contact surfaces obtained based on 10 repetitions are shown in Figs. 7 and 8.

The influence of the grinding depth on the wear resistance of the machined surfaces is not expressed in the same way for all the three values of feed speed v_r. At the smallest speed of machined piece relative motion, wear of the corresponding machined surfaces increased with increasing grinding depth. However, at higher speeds v_r the change of grinding depth does not result in a unique change of tribological behavior of machined surfaces.

These results can be explained by the consequences of the cutting process on the surface micro geometry and the physical - mechanical state of material in the surface layers. For different combinations of the grinding regime elements, either influence can be the more dominant.

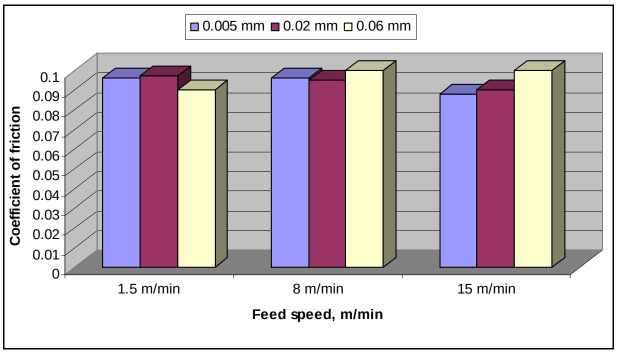

Figure 6. Friction coefficient versus parameters of grinding

Surfaces that are obtained at the smallest value of v_r have very similar structural and other characteristics of roughness. The differences seen in the wear resistance are, in this case, a consequence of the thermal influence of machining on the relaxation of material in the surface layers, and the decrease of the micro hardness (Fig. 5).

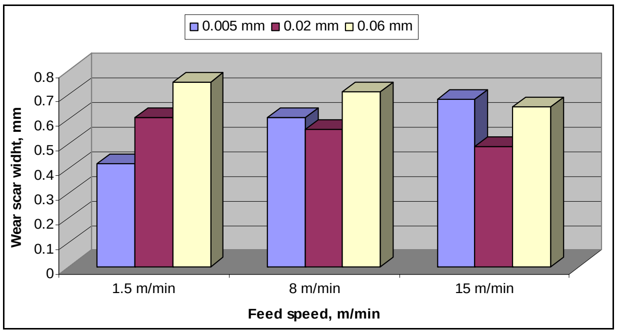

Figure 7. Influence of feed speed upon grinding surface wear

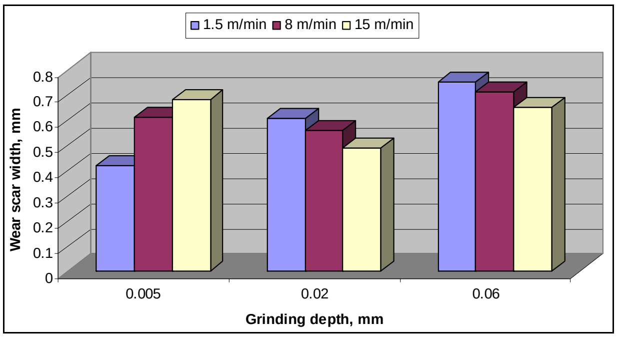

Figure 8. Influence of grinding depth upon grinding surface wear

Differences in the wear resistance of surfaces obtained at higher v_r are a consequence of both differences in structural characteristics on the surfaces roughness and the uneven thermal effects of the surface layers micro hardness. Due to the short time of the thermal influence in these cases, the more prominent mentioned process of micro hardness decrease is possible only at the largest grinding depth ($\delta = 0.06$ mm). This explains the increase of the degree of wear with the change of the grinding depth from $\delta = 0.02$ mm to $\delta = 0.06$ mm. However, the reason for the wear degree increase, which corresponds to surfaces obtained at the smallest grinding depth $\delta = 0.005$ mm, lies in the poor characteristics of the surface roughness structure, what is shown in Fig. 4.

Diagram in Fig. 8 makes possible the analysis of influence of the grinding conditions on tribological properties of the machined surfaces to be completed. One can notice immediately that the influence of the speed v_r change on the wear resistance of the machined surface can have completely different nature for different grinding depths.

The first part of the diagram ($\delta = 0.005$ mm) illustrates the case of "pure" effect of micro geometrical differences of the machined surfaces on their tribological properties. Machining at this grinding depth, regardless of the value of v_r is characterized by the low levels of the thermal loading, so the change of state of material in surface layers does not occur. Thus, the differences in structural characteristics that arose can be explained by the mentioned differences in structural characteristics of the surfaces micro geometry. For the two following grinding depths $\delta = 0.02$ mm and $\delta = 0.06$ mm the increase of the speed v_r expresses completely opposite influence on the wear resistance, what is the consequence of the dominant thermal effect of the grinding process which is increasing with decrease of the speed v_r.

5. CONCLUSION

The results show that the contact surfaces obtained for different combinations of the grinding regime parameters, in spite of belonging to the same roughness class, (they even have a similar level of the friction coefficient corresponding to them), have very different wear resistances. This is a consequence of the different structural characteristics of roughness, as well as of the change in the material micro hardness in the surface layers, which are a result of the changed machining conditions.

According to the above, by relying only on the roughness class of the contact surfaces, obviously one neglects the tribological aspect in the essential phase of creating technical systems – the phase of design. In order to realize tribologically advanced technical systems, it is necessary to respect the whole list of tribologically relevant criteria, which, besides the conventional height parameters and basic material hardness, includes, above all, the parameters of structure and shape of micro roughness and the physical - mechanical state of material in the surface layers.

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