Behavior under contact loading of surface asperities obtained by turning

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Abstract. The quality of metallic surfaces is described by the physic-mechanical and chemical state (microhardness, microstructure) and geometrical state. Contact interaction between two solid bodies has a very important role in many physical phenomena and engineering applications. The main idea of the research was to experimentally study the behavior at pressure of a surface obtained by turning. For this experiment, cylindrical parts made of aluminum were used. The test samples were obtained by turning using tools having distinct corner radius and distinct feeding rates. Experimental method was applied in order to evaluate and model the influence exerted by some input factors (force, turning tool corner radius, machining feed) on the *Ra* surface roughness parameter. By using the data obtained after the experimental tests, an empirical mathematical model able to describe the evolution of the roughness under pressure contact was determined.

1 Introduction

The surface roughness consists in an assembly of micro-irregularities with a reduced pitch in comparison with its depth, which forms a certain relief of surface. The surface roughness is significant for knowing how an object will interact with its environment. Unlike the smooth surfaces, the higher friction coefficients of the rough surfaces will cause more wear on this type of surface. Roughness frequently is a right benchmark to determinate the performance of the mechanical element, because the irregularities of the surface may “thrive” in time and form cracks or corrosion. [1]

Various parameters could be used in order to characterize the surface roughness. One of them is arithmetic mean deviation of profile, which is universally recognized and most used parameter of surface roughness. It is defined as an arithmetic mean of the absolute deviations of the roughness profile from the mean line *Ra*.

The mechanical contact is an important concept in the field of engineering. It is agreed that two or more distinct entities (solid bodies) are in contact as long as there is a common

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surface that is separating them without any material transfer from one solid to another. Two rough surfaces are in contact on a small area that is composed by all the contacts between the asperities (which will deform).

According to the rigidity of the surfaces, the contact between them can be rigid-flexible. A rigid-flexible contact is defined by the fact that one of the surfaces that are in contact is more rigid than the other. One of the main applications of the contact analysis refers to the subject of quality [2].

Many researchers have addressed issue of contact with or without friction between two elastic solids. Hertz was the first that solved this issue for a frictionless contact between smooth solids, claiming that the point of contact between two spheres of radius r becomes an area of contact. The explanation of Bowden and Tabor (in 1939) was simple, claiming that the asperities of two rough surfaces reach the field of plastic deformation as soon as the asperities get in contact, noting the existence of a direct proportionality between the load and the contact area of the bodies get in contact [3].

The main objective of the present paper was to highlight the influence exerted by several factors (feed, tool corner radius and force) on the surface roughness, respectively on the behavior under contact loading of surface asperities.

2 Hypotheses concerning the influence of various factors on the surface asperities accuracy obtained by turning

When two surfaces are in contact, the real area of contact is not the nominal one, but the resulting area of asperities found in contact [2].

It can be observed that when they are pressed against a rough surface with another cylindrical body that has a higher hardness, the asperities of the initial surface are reduced/flattened. The main factors considered in this study that have influence on the roughness in the turning machining are the following: the processed material, the pressure between bodies found in contact, the feed and the turning tool corner radius. These factors can be taken into consideration as input data. In order to observe the surface roughness modification under contact loading, the test pieces surface were pressed with another rigid body. The force used for pressing against the surface is also an input factor that will influence the flattening of the initial surface asperities. The required result is to obtain a surface with “lower” asperities, compared with the initial ones that is expressed as an output data and that consists of the modified value of Ra surface roughness parameter. For illustrating the correlation between input and output parameters, it can be used a systemic analysis (Figure 1).

As known, a higher tool corner radius and a smaller turning feed will determine a smaller roughness at facing the test pieces.

By summing the above mentioned statements, three cases of material behavior can be described by considering the compression force and the value of roughness parameter:

- The first case, where the compression force has a reduced value, and the asperities are stressed in the elastic domain;

Fig. 1. Systemic analysis of input and output.

- The second case, where the compression force is highly enough to deform the asperities in the elastoplastic domain, producing a flattening of the superficial layer. Much higher strains are produced if the force goes in the plastic domain;
- The third case and the most “hazardous” where the compression force is high enough to crush the asperities of the sample and mark the form and roughness of the punch (pressing tool).

The way in which a rigid body presses on rough surfaces is represented in Figure 2.

One can assume that once with the increasing of the contact loading, respectively of the pressure between the rigid body and the asperities of the test piece surface, a smoother roughness will be obtained.

Fig. 2. Pressing with a uniform force on a flat surface.

3 Experimental research

The experimental research aimed to evaluate the contact behavior at pressure of a surface asperities obtained by turning.

For the experimental study, it was used an upright drilling machine as an equipment able to offer the necessary force/pressure (Figure 3). One considered initially that during experimental research, a force up to 500 [daN] could be necessary in order to generate

Fig. 3. Drilling machine used as a pressing machine.

plastic deformation of the surface asperities. Four test samples of aluminum and a cylindrical pressing tool made of high speed steel were also used. The aluminum was selected as test samples material due to its high plasticity, adopting the hypothesis that under the pressure action, the surface asperities will be affected by a process of plastic deformation. The cylindrical test samples had thickness $s=10$ [mm] and an external diameter 25[mm]. An hole with a diameter 5 [mm] was achieved in each test sample, in order to simplify the process of frontal turning.

The samples were prepared on the frontal surface using two feed values (0.24 mm / rev and 0.48 mm / rev) during turning process and two cutting tools with distinct tool corner radii (0.4 mm and 0.8 mm). Firstly, it was measured the roughness of the initial surface of test

samples by using an electronic roughness tester (Mitutoyo SJ 201) to determinate the value of this parameter. The second stage was the pressing stage, where in first instance pressing forces with values of 250 [daN] and then another one with 462 [daN] were used. In order to generate the plastic deformation of the test samples surface asperities, a cylindrical pressing tool having a diameter of 2.95 mm was used. It was expected that using the hardened high

speed steel as material for pressing tool and not very high value of the pressing force, the pressing tool material will not be affected by plastic deformations.

Fig. 4. Image concerning surface roughness of the sample: 1- asperities corresponding to the feed movement of turning process; 2- surface generated by pressing a cylindrical body with a known force.

The result pressure exerted by the cylindrical body determined a visible change in the frontal aspect of each test sample (Figure 4). All forces were generated by using a dynamometer. Finally, using the same electronic surface roughness tester, the roughness corresponding to the surface generated by plastic deformation of the test sample material was measured.

The values of feed f , radius tool r_ϵ and force F were inscribed in Table 1, for each of the eight experiments. The last columns from this table included the sizes of the surface roughness parameter determined by measurements and corresponding to the initial and final surface states, respectively. Every roughness parameter was measured three times and the final value was settled as arithmetic mean of those three values.

To determine the empirical mathematical model able to show the influence exerted by the three independent variables on the R_a surface roughness parameter, specialized software was used [4]. This program uses the least square roots method to determine the most suitable equation for certain experimental research. The output of using the program consists in several types of equations that are possible mathematical expressions corresponding to the given input.

Fig. 5. Pressing with a cylindrical tool on the frontal surface of the sample.

Table 1 Experimental conditions and results

Exp. no.	Input parameters				Output parameters
	Feed f [mm/rev]	Tool radius r_ϵ [mm]	Force F [daN]	Initial surface roughness parameter R_a [μm]	Final surface roughness parameter R_a [μm]
1	0.24	0.4	250	5.12	2.32
2	0.24	0.4	462		0.84
3	0.24	0.8	250	11.28	1.42
4	0.24	0.8	462		1.20
5	0.48	0.4	250	17.87	2.79
6	0.48	0.4	462		2.11
7	0.48	0.8	250	22.35	3.89
8	0.48	0.8	462		2.93

Considering that in machine manufacturing there is a real preference to use power functions when elaborating empirical mathematical models, we selected such a function to model the influence exerted by the machining feed f , tool corner radius r_ϵ and force F on the value of R_a surface roughness parameter:

$$Ra = 30.65 f^{1.41} r_{\epsilon}^{0.518} F^{-0.178}$$

(1)

This mathematical empirical model was used to elaborate the graphical representations from Figure 6,7 and 8.

Fig. 6. Influence exerted by force on *Ra* surface roughness parameter (*f*=0.24 [daN]).

Fig. 7. Influence exerted by force on *Ra* surface roughness parameter (*r_ε* = 0.8 [mm]).

Fig. 8. Influence exerted by feed on *Ra* surface roughness parameter (*r_ε* = 0.4 [mm]).

The analysis of these graphical representations and of the empirical model constituted by the relation (1) shows that the most important factor able to influence the value of the *Ra* surface roughness parameter is the machining feed *f*, since the value of the exponent attached to this factor has the maximum value compared to the values of the exponents attached to the other factors. One could notice that as expected, when the machining feed *f* increase, the value of the *Ra* roughness parameter corresponding to the plastically deformed surface increase also, since the value of the exponent attached to the size *f* is positive. The increase of the value of tool corner radius determines a growth of the rough parameter value in that the narrowing between the peaks of asperities is reduced.

4 Conclusions

We could say that character of a produced surface is highlighted by the precision of the process with fulfill of the dimensions defined in the technical documentation. Each machining process leaves particular pattern of the machined outer. This pattern is known as surface roughness. When two manufactured surfaces are in contact, surface finish of the mating elements is a significant factor in the performance and behavior of the matching elements. The roughness of a machined part occurs as a result of the following factors: cutting conditions parameters (feed, cutting speed, cutting depth), tool geometry, vibrations generated in the technological system which consists of machine tool, cutting tool and workpiece. Thus, it can be assumed that surface roughness determines the quality of contact interaction between two solid bodies which plays an important role in many physical phenomena and engineering applications.

Within this paper, we presented some research results concerning the contact behavior between a cylindrical pressing tool made of high speed steel and test samples made of aluminum on 8 experiments, where we settled as a combination of three main process input factors (machining feed, tool corner radius, force), each of them taking, one by one, two values. We measured the initial roughness of the front surface of test samples, then we pressed the pressing tool on this surface with two values of force and after that we measured again the roughness of the new surfaces created by plastic deformation of the asperities (Figure 5). We found out the function that expresses the influence exerted by the input factors on the Ra roughness parameter valid to the plastically deformed zone of the test sample. In this way, the power function determined as empirical mathematical model revealed us that all input factors are able to significantly affect the values of the Ra roughness parameter of the deformed zone.

In order to illustrate the above mentioned influence, we realized three graphical representations, where f , r_e , and F were used, one by one, as independent variables in the power type function valid for the Ra surface roughness parameter. We have observed that the main influence on roughness is exerted by the machining feed. If the feed increases, the roughness increases too (Figure 8). This variation of the Ra surface roughness parameter is also valid for the tool corner radius. Another thing that we have observed refers to value of the force. Thus, as much as the pressing force grows, the values corresponding to the Ra surface roughness parameter reduces, also (Figures 6,7).

In the future, we could study the influence of the same or other input factors on other surface roughness parameters, like Rz , Rq , Ry are or even on factors able to better characterize the contact surfaces.

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