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HARDENING OF SURFACE LAYERS

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Abstract: The present paper deals with the hardening of surface layers after machining. At the beginning residual stresses, which affect the status of a surface layer, are described. The Hertz contact pressure theory and the matter plastic deformation by the hardening of surface layers is explained. The methods and technical devices chosen for the mechanical hardening of surface layers are described along with the analysis of their technical features. A tool was created for the hardening of the surface layer and an experiment was carried out which verified its effect.
Keywords: surface layer, residual stresses, hardening of surfaces, stress, plastic deformation

INTRODUCTION

During the machining of plastic materials, the area of plastic deformation penetrates into the work-piece layers that are under the cutting edge. Plastic deformation of metal materials is always connected with a change in hardness and with the occurrence of residual stresses. The main mechanism of plastic deformation is the slip caused by the slipping motion of dislocations. The reasons for the experimentally observed complex form of the stress – deformation interdependence are to be found in the changed conditions of the motion of the dislocations. Plastic deformation is connected with significant hardening. The more the hardening, the lower yield point, and the hardness can be explained by different concepts including the impact of deformation conditions (mainly the temperature, size and speed of the deformation), as well as by the interrelations between the mechanical properties and the structure of the material in terms of the size of the grain, the dislocation density, etc. The hardness of the layer is significantly higher, its roughness is lower, etc. In some materials, the surface hardness of the machined material is 30% higher than the hardness of the basic material of the work-piece.

THEORETICAL CONSIDERATIONS

The most frequently used methods of strengthening are the following: shot peening, roll burnishing, very thin machining, pull broaching, push broaching and ballotining. Although these methods are methods of mechanical cold working of the thin surface layers of components after machining, they are included as machining processes because they are mainly performed at machining machines, are often connected with machining operations and are a part of their technological processes. Their common objective is to improve the quality of the surface layers of components. As a result of the incidence of a hard ball on a surface with the force of the ball's action equal to F, according to the magnitude of F, first an elastic deformation of the surface occurs and then a plastic one (the curve OAB at the Fig.1) [3]. Because plastic deformations occurred, the relieving process proceeds along the BC curve. The residual plastic deformation is manifested by the impression dimension d that corresponds to the dimension OC. Plastic deformation below the impression is evenly distributed, as if copying the ball's surface, not taking friction into account. The depth of the material compression h is proportional to the depth of impression h_1, i.e., $h = mh_1$. According to the conditions of the technological process, the coefficient $m = 2 \ldots 20$. The calculation of the stress in the surface layer is derived from the course and size of the deformation. Under a sufficiently large cover, the course of the stress below the surface is similar to that below the impression. The actual distribution of the pressure stresses is the result of plastic deformations in the surface layer and in deeper layers due to Hertz's pressures.

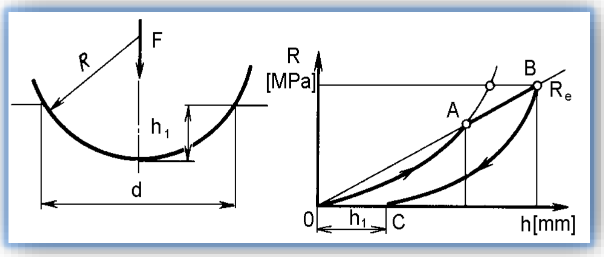

Figure 1. Surface changes due to the incidence of the ball on the surface and the course of the elastic and plastic deformations due to stress [2]

As early as the year 1881, Heinrich Hertz formulated the relation between the load value of the projected area of the surface pressures and contact of generally curved bodies. The solution derived by Heinrich Hertz only gives the orientation values of the contact pressures. The place of the highest stress is under the middle of the upper surface of the point of contact between the bodies, and the accumulation of stress is near the outer surface. The modulus of elasticity in the tension of both materials is constant; it does not vary with the load. Strains are very low in relation to the sizes of the bodies and their profile is in one plane (Hertz 1896). For the calculation these four laws defined by Heinrich Hertz the following must hold:

- isotropy and homogeneity of projected area material,
- over the course of deformation, Hooke´s law must be valid,
- shear stress is equal to zero. The influence of friction is not specified,
- projected areas are equal.

Two spherical bodies are contiguous at only one point. Owing to the load and deformation of the bodies, the point contact morphs into surface contact [2] (Figure 2). This surface is elliptic.

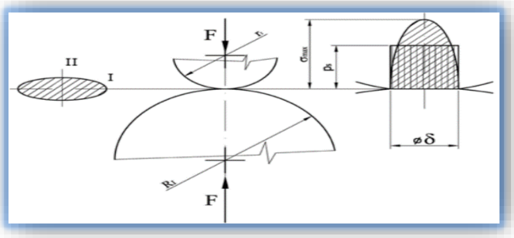

Figure 2. Diagram of the point of contact

DESCRIPTION OF EXPERIMENT

The physical and geometrical parameters as well as the turning parameters of the rotary work-piece remained constant during the experiment while variables such as the force F of the forming tool, the average dimension d of the forming tool, the feed f of the forming tool, and the material of the forming element were changed. The outcomes to be measured were the roughness of the surface Ra after each turning and forming operation, the Vickers hardness after machining operation, and the wear on the tools after hardening. The experiment consisted of the following activities:

- turning of the work-piece,
- hardening the surfaces of the rotary work-piece with the ball under various conditions,
- evaluation of the surface layers of the work-pieces after turning operations and the application of a static roller,
- comparison of the wear on the forming tools.

For the experiment, a hardening tool with damping was developed, consisting of the following parts [1]:

- a cage – material 7050 (aluminum),
- Linear housing Bosch Rexroth STAR ø20 (067-20),
- a round tool ø20 material steel Cf 53,
- forming element – balls for bearings, material: steel and Si_3N_4, with 2 diameters of 6 and 8 mm,
- dampening member – polyurethane material, hardness 85 + / -5 Shore A

For each type of shaping element two feeds were chosen, and for each feed the same three forces were selected, based on their calculated power during the process. Hardening of the samples was carried out under constant lubrication with Ekolube CPN 211 high quality cutting oil, which is a concentrate of high pressure additives (chlorinated paraffin, etc.) used in the machining of very tough materials. After the completion of the strengthening operations, the surface roughness, Ra_2, of each sample was measured using a profilometer. The roughness of each sample was measured 10 times in order to obtain the relevant average data on the roughness of the hardened samples.

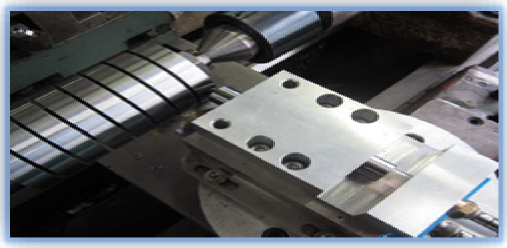

Figure 3. The tool for the strengthening of surfaces with a dynamometer to determine the contact force, and on the right, a detail of the ball

Figure 4. Measurement of roughness with a profilometer and the Vickers hardness measurements

CONCLUSIONS

The parameters of roughness after hardening with a bullet confirmed the assumption that the micro-roughness of the work-pieces would be smoothed (reduced values of the surface roughness were produced). Particularly low values of surface roughness were obtained when using the ceramic cutting tool (silicon nitride), which demonstrates the very good physical properties of this material.

Thanks to the properties of the ceramic tool (high hardness, durability, and resistance to high temperatures, wear and mechanical stress) reduced surface roughness was achieved with minimal compressive force. Reduced surface roughness was produced using a ceramic tool with minimal compressive force compared with the use of a steel ball. The roughness was already less using the minimum contact force compared to using a steel ball. The best surface roughness values were achieved with the bullet made of silicon nitride with d = 8 mm, f = 0.08 mm / rev. and shaping forces of 700 and 1000 N (value of Ra = 0.23 microns and 0.27 microns, respectively).

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