Cold deformation smoothing of the cylindrical external surfaces by mechanical shocks

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ABSTRACT: The objective of this study is to present a cylindrical exterior surfaces finishing method using repetitive mechanic shocks. The structural changes of the surface layer during impact and after the tools are retracted had been studied. The necessary mechanic shocks are obtained using balls or reels inserted in metallic disks. A mathematic relation that evaluates the micro-irregularities height of the final work piece is presented in the end.

Key words: surface roughness, smoothing, mechanical shocks, plastic deformation

1 INTRODUCTION

Cold plastic deformation of the superficial layer in any metal material aims to improve not only the micro- and macro- geometry of the surfaces, but also to enhance the physical-mechanical and physical-chemical properties of the work pieces as well [1,2].
Deformation by mechanical shocks is a complex phenomenon that includes dynamic interactions between the metallic structure of the tool and the work piece [3].
Cold deformation smoothing by mechanical shocks is considered a simple and efficient method to smooth and harden different types of surfaces [4,5]. The method can be successfully applied on cylindrical (internal / external) and plane surfaces, as well.

2 THE TECHNOLOGICAL EQUIPMENT

The main element of the technological equipment used in plastic cold deformation by mechanical shocks is represented by a special device which could be installed on a universal machine-tool (lathe or milling machine) and depends of the type of surface to be processed, i.e. cylindrical or plane. For a cylindrical external surface, the device is fitted on a universal lathe, as shown in figure 1. The device has an electrical engine that ensures the rotation of the tool (ball-holder disk) using a cinematic transmission.

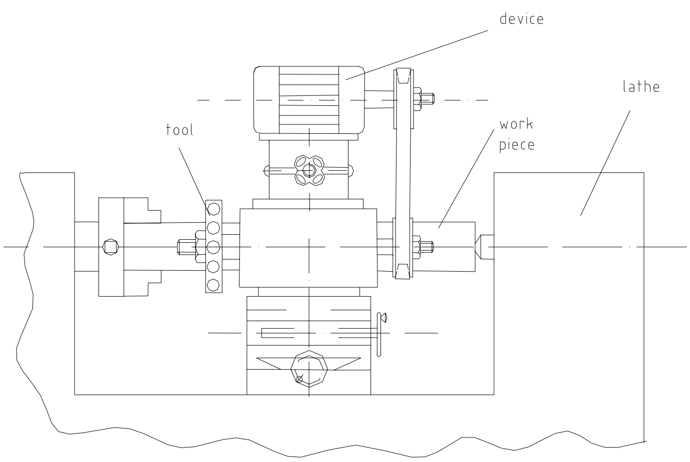

Figure 1. The cold plastic superficial deformation the device scheme.

The disk-tool is positioned very close to the surface of the studied element allowing to the balls from the disk channel to hit the work piece during the rotation movement.
Hitting frequency depends on the disk's number of rotation per minute and also on the number of the balls on the disk-tool.
A schematic representation according to micro geometry shaping of the surfaces processed using

cold plastic deformation, is shown in figure 2.
The process is based on the principle of superficial layer metal particles movement under the action of the pressure forces. The process focuses on the prominent areas of the work-piece aiming to the equalization and standardization of the surface [6].

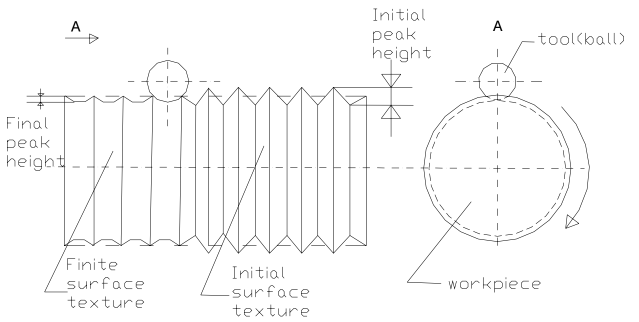

Figure 2. Shape schematization of micro profile.

3 MICRO-PROFILED SURFACE CHARACTERISTICS AFTER PROCESSING

The friction contact Mindlin theory [7] proves that the linear and circular tool movement produces tangential traction moments, as shown in figure 3. The tangential roughness depends on the normal applied pressure while the tangential tractions depend on the friction coefficients of the work piece and tool material. In order to eliminate these inconveniences, we consider the deformations small and the friction static.

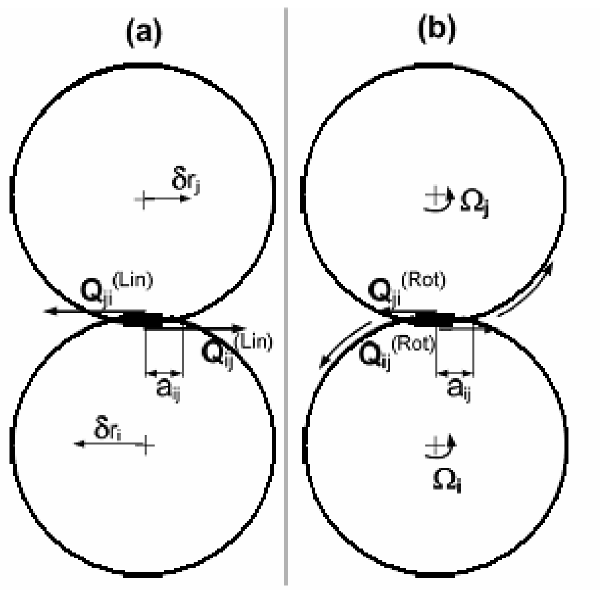

Figure 3. Spheres at elastic impact. a) different rotation value; b) same rotation value.

Photo-elastic analysis of the contact tensions indicates that their distribution is the same as the one inside a ball bearing.
Figure 4 analyzes the tensions in two different situations: the first case is the vertical impact between the ball direction and the surface of the work piece (left side), while the second one investigate the lateral impact (right side).
The profile of the crater shown in Figure 4, simulated with a finite element code, is obtained after one single impact revealing that the lateral hit ("sliding" impact) causes an uneven grains distribution, mainly when the ball is leaving the cavity. The vertical impact produces a uniform movement of the grains, resulting in a symmetric crater.

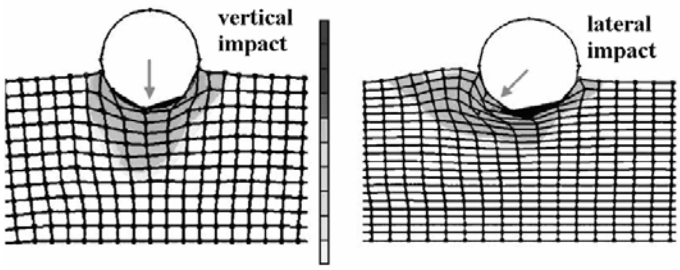

Figure 4. Finite Element Method (FEM) analyze of the impacts: vertical impact (left side) and lateral impact (right side).

Intensifying the collision force, one observes that the depth of the crater formed during the "sliding" impact becomes smaller and the length bigger. The FEM investigation was made under the following assumptions: the ball has only one contact with elastic-plastic surface and its velocity is increased systematically; one remarks that the smoothing of the deformed layer depends on the tool speed. When the "sliding" speed becomes important, the depth of the deformed layer decreases, and the crystalline structure of material suffers less modifications, leading to piece hardening.
The rotation speed during the working process influences not only the manufacturing productivity but also the quality of the final surface. The rotation speed of the material depends not only on the uniformity of the traces resulting after the contact with the balls but also on the deformed layer homogeny. High speed manufacturing is limited by the heat produced after the interaction between the material surface and ball's micro-irregularities and also by their wear as a result of the contact. Increasing the processing speed decreases the plastic deformation rate. Between plastic deformation

propagation and deformation speed appears a difference, concluding with the decrease of the plastic deformation rate and increase of the elastic deformation rate.

When the rotation speed of the work piece is small the plastic deformation dominates and the effect of the hitting ball on the surface unit reside more time compared with the high speed case. As a result, the propagation of the plastic deformation is more uniform and to a bigger depth.

The feed motion S of the longitudinal tool or of the piece is one of the most important parameters influencing the roughness of the surface under investigation, because the micro-irregularities height depends directly on it and on the radius of the deforming ball, as indicated by the axial section from Figure 5. The piece feed motion is the most important parameter to be considered in every analysis because it influences directly any variation of the contact height. Further, it affects the periodic modification of the deforming forces and the elastic-plastic deformation of different material micro-areas.

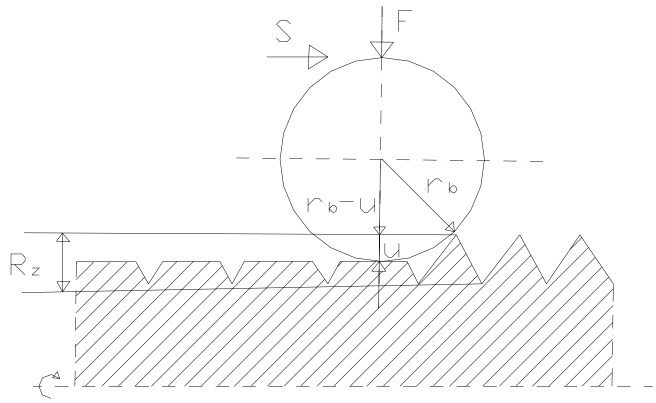

Figure 5. Geometric process model.

This processing with mechanical shocks inducing a desired surface smoothness and hardening the superficial layer to a given depth depends on the hitting intensity transmitted to the work piece material and on the weight of the hitting balls. The force produced by the balls is applied on a perpendicular direction of the symmetric axe.

Due to elastic behavior and oscillating moves of the deforming ball, directly connected with the feed motion of the tool, the asperities profile is complex. In fact, the elastic return of the material appears randomly in different parts of the profile which is the main cause of its complexity. Nevertheless, one observes a tendency of the metal to elastic recovery at the top (Δh_{ev}) and at the bottom (Δh_{ef}) of the micro-irregularities, as shown in figure 6.

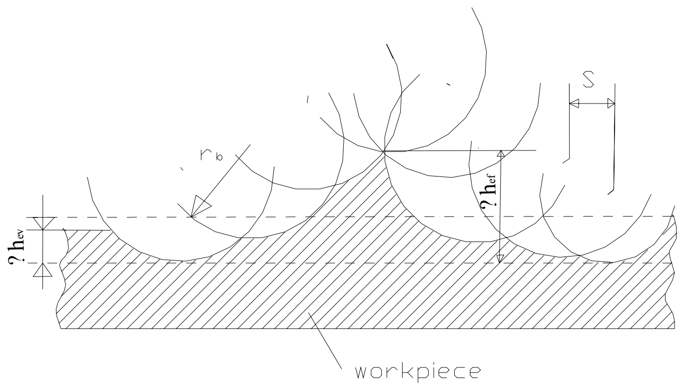

Figure 6. Profile generation scheme

Starting from the tool geometry and using the general scheme of tool-work piece contact, as shown in figure 5, one can establish the equation of the deformed surface in the contact zone.

We considered that the radius and the physical-mechanical properties of the deforming ball remain unchanged during the whole process. Also, the elastic deformation range on the contact section is assumed to be the same for all contact lengths. The maximum value of the irregularities height can be calculated using the equation:

$$h_{\max} = h_m + \Delta h_{ev} - \Delta h_{ef} \quad (1)$$

where h_m is the theoretical value of the micro-irregularities height, Δh_{ev} is elastic recovery on top and Δh_{ef} correspond to elastic recovery at bottom.

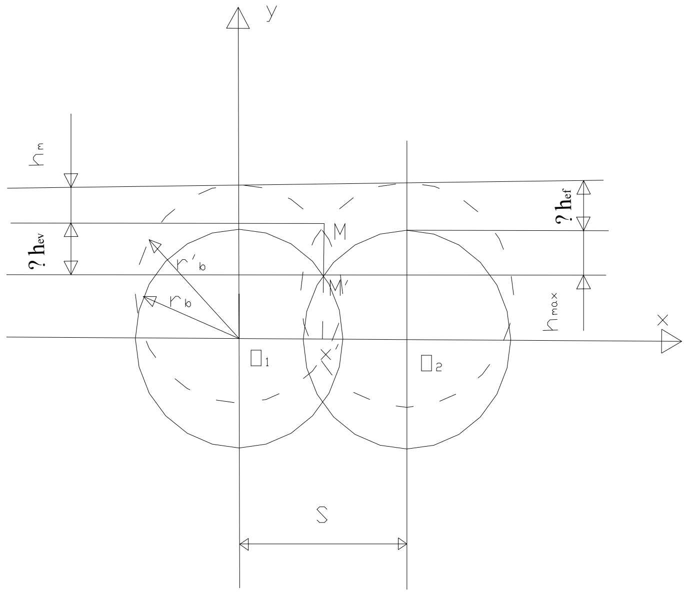

Figure 7. The theoretic determination of the micro-irregularities height value

The coordinates of the point M (see Figure 7) are introduced in the general form of the circle's equation determining the relation:

$$\left(\frac{S}{2}\right)^2 + \left(r_b^1 - h_{\max} - \Delta h_{ef}\right)^2 = \left(r_b^1 - \Delta h_{ef}\right)^2 \quad (2)$$

A straightforward calculation leads to:

$$h_{\max} = r_b^1 - \Delta h_{ef} - \frac{\sqrt{4r_b^1\left(r_b^1 - 2\Delta h_{ef}\right) - S^2}}{2} \quad (3)$$

Using equation (1) it can be determined the range of the elastic return on the top of micro irregularities. So, replacing equation (3) in (1) one can determine the theoretical value of the micro irregularities height:

$$h_m = r_b^1 - \Delta h_{ev} - \frac{\sqrt{4r_b^1\left(r_b^1 - 2\Delta h_{ef}\right) - S^2}}{2} \quad (4)$$

From equation (4), one can establish the theoretical value of the micro irregularities height. In addition, relation (4) shows how this height is precisely influenced by the tool feed motion and the deforming ball radius.

Finally, in the case of the plastic deformation one may obtain waves on the surface material which are determined by the manufacturing regime or by the non-uniformity of the material roughness. Other factors that could influence the properties of the waves are low quality of the initial surface to be manufactured and the self vibrations of the system used. The characteristics of the waves are mainly affected by the feed size and the clearance of the axial deforming ball inside the manufacturing tool channel.

4 CONCLUSIONS

In this paper, we have presented the analysis of the circular surfaces micro-profile generated on the work piece machined device.

We observed that the shape of the micro-profile depends not only on the external parameters, but also on internal processes. The detailed analysis of the effect defined by the internal process on the surface roughness and hardness shall be provided in a further paper.

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