Examination of Surface Roughness of Burnished Workpieces

Gyula VARGA¹, * - Ferenc SZIGETI² - Gergely DEZSŐ³

Abstract: This study deals with the process of diamond burnishing. It contains with the examination of the effect of technological parameters of burnishing on the surface roughness of the burnished surface. A new dimensionless parameter, the improvement ratio of surface roughness, was determined for the evaluation of the effectiveness and goodness of the sliding burnishing process. Applied burnishing parameters were: burnishing speed, burnishing feed, and burnishing force. By the use of Factorial Experimental Design new empirical formula was determined for the improvement ratio of surface roughness which is valid in between the minimal and maximum parameters of the input parameters. Graphical demonstration and the evaluation of the measuring results closes the paper.

Keywords: Burnishing, factorial experiment design, surface roughness, burnishing force

1 INTRODUCTION

An innovative cutting manufacturing process integrates aspects such as industrial safety and efficient use of operating aids apart from the productivity and quality. Crucial factors of influence concerning this problem are
- the efficient lubricant use and
- the solid waste and noise emissions’ minimization. [2]

It requires the environmental oriented monitoring in the manufacturing company [16] and the optimization of maintenance management [22]. By application of wear-resistant complexes by modifying its surface properties the improvement of working efficiency of cutting tools can be determined [24]. Also important activity in the innovative manufacturing processes the evaluation of machine tool quality [11] and different machining procedures such as rotational turning [19] and hard turning [26], furthermore optimization of manufacturing operations e.g. milling [12].

The engineering components are frequently subjected to high levels of loads and temperature [5]. The technological quality of machined component can be evaluated by the surface quality [4] and surface integrity [10]. Finishing surface machining procedures differ in their capabilities in their
- mechanical and thermal damage,
- residual stresses and
- materials [9].

According to the kinematics of burnishing it can be classified into two groups:
- dynamic, and
- static [3].

According to the deformation element the burnishing process can be classified:
- ball burnishing,
- roller burnishing

According to executing mechanisms finishing surface machining procedures can be divided into two types:
- which involves material loss such as grinding [14], honing [17], rotational turning [19], hard turning [26],
- which depends on plastic deformation of the surface where there is no material loss [5].

According to the localization of the surface to be burnished, it can be:
- outer cylindrical surface,
- inner cylindrical surface, and
- flat surface.

Burnishing is an example to the second one (Fig.1) [15].

The advantages of diamond burnishing are:
- the wear resistance and fatigue stress improves [7],
- the mechanical features of the workpiece are improved as well [13],
- the surface of the workpiece will be smooth because its layer undergoes on an intensive plastic deformation [1].
- cost effective method, it can easily be applied [13].

The analysis of ball burnishing can effectively be performed as an interesting application in the flexible manufacturing system [8] by the adaption of machinability investigation of metal matrix composites [18].

Burnishing can be used for different workpiece materials, such as aluminium, bronze, polymers, brass, titanium, nickel, copper and different types of steels [3], [21].

Tools used in these processes can be constructed into
- a fix system, or flexible, supplied with a calibrated spring [25].
The quality of burnishing depends on a lot of input parameters, among them can be found as follows:

- burnishing operation parameters [23]
  - speed,
  - feed,
  - force,
  - number of passes;
- material of the burnishing tools
  - PCD,
  - carbide,
  - ceramic;
- shape of the burnishing tools
  - spherical,
  - semi-cylindrical;
- dimension of the tip,
- machine tool, and
- lubricant type and viscosity. The task of optimization requires a great number of experiments, when even only a few parameters are taken into account. By using Taguchi type experimental design [3], [20] model the response function can be determined which is valid in between the minimum and maximum values of the input parameters. In our experiments the input parameters were:
  - burnishing speed, \(v\),
  - feed, \(f\), and
  - burnishing force, \(F\),
and the output parameters were:
  - surface roughness (SR),
  - machine tool, and
  - lubricant type and viscosity. The task of optimization requires a great number of experiments, when even only a few parameters are taken into account.

In our experiments the input parameters were:
  - burnishing speed, \(v\),
  - feed, \(f\),
  - burnishing force, \(F\),
and the output parameters were:
  - surface roughness (SR),
  - improvement ratio of surface roughness (I).

2 EXPERIMENTAL WORK
2.1 Experimental conditions

The experimental setup of sliding burnishing is shown on Fig. 2.

![Fig. 2. Experimental setup of the sliding burnishing](image)

Workpiece material is steel C45, its chemical composition is shown in Table 1. Before burnishing the surfaces of the specimen were grind. Geometrical dimension of specimen is shown in the middle of Fig. 3.a and Fig. 3.b. Each specimen contained 5 different experimental surfaces. Among them 1-4 could be used for the examination of different operational parameters and on the 5th one the features of the ground surface remained. The outer dimensions of the specimen were \(D = 49\) mm and \(L = 190\) mm.

OPTIMUM D420x1500 type universal lathe was used as the machine tool for burnishing experiments.

The surface roughness of the workpiece was measured by the TalySurf520 3D surface roughness measuring equipment (Fig. 3.) after grinding (before burnishing) and after burnishing. All the measurements were executed on a surface having 2.0x2.0 mm dimensions on five different positions on the periphery of the workpiece, which average was calculated in all cases. The improvement of the Root-Mean-Square Deviation of the Surface \(S_q\) was determined after definition of the improvement ratio of surface roughness \(I_Sq\):

\[
I_Sq = \frac{S_{q_b} - S_{q_a}}{S_{q_b}} \cdot 100, \ % \quad (1)
\]

where:

- \(I_Sq\) is the improvement ratio of surface roughness \(S_q\)
- \(S_{q_b}\) is the surface roughness \(S_q\) before burnishing
- \(S_{q_a}\) is the surface roughness \(S_q\) after burnishing

![Fig. 3. Measurement with the TalySurf520 3D surface roughness measuring equipment](image)

2.2 Experimental design

In the applied Factorial Experiment Design the chosen values of the input parameter intervals were:

- burnishing speed \(v=180\) m/min ÷ \(277\) m/min;
- feed \(f=0.05\) mm/rev ÷ \(0.10\) mm/rev; and
- burnishing force from 45 N up to 82 N (Table 1).

when the kinematic viscosity of the friction reducing oil was: \(\nu=70\) mm²/s. In this examinations the number of passes of burnishing was only one.

The adjusted values of input parameters are shown in Table 1.

The parameters measured on the 3D measuring machine can be recorded according to ISO 25178 standards as well. The ISO 25178 standard deals with the surface roughness parameters [27]. Five main parameter groups are in the standard ISO 25178 (Fig. 4.).

![Table 1, Matrix of experimental design](image)
The measured values of the experiments are in Table 2. and Fig. 6. As the independent input parameters, it contains the dimensionless coded parameters too.

### Table 2. Results of the measurements

<table>
<thead>
<tr>
<th>No of exp.</th>
<th>Coded values</th>
<th>Sq, µm</th>
<th>Before</th>
<th>After</th>
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<tr>
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<td>x₂</td>
<td>x₃</td>
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<td></td>
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<td>0.2482</td>
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</table>

In Table 2 the coded values relate to the investigated actual parameters, where -1 means the lower value while +1 the upper value of the parameter.

Measured average surface roughness values of the ground workpieces (before burnishing) are:
- \( Sq = 0.4575 \, \mu m \), which is used for experiments done by \( F = 45 \, N \) burnishing force,
- \( Sq = 0.4478 \, \mu m \), which is used for experiments done by \( F = 45 \, N \) burnishing force.

The left side of Table 2 demonstrates the 3D surface topography pictures in case of 42 N burnishing force and the right side demonstrates ones in case of 82 N. On the basis of 2 mm x 2 mm surfaces. According to the equation (1), the ISq improvement ratio of surface roughness was calculated from the measured data. From the ISa value the empiric formula (3) was determined with the method of factorial experiment design.

### 2.3 Results of measured data
Fig. 5. Surface topography after burnishing, a) burnishing force $F=45$ N, b) $F=82$ N

\[ ISq = -23.197 + 1.464 \cdot v + 1.165 \cdot 10^3 \cdot f + 1.068 \cdot F + 16.52 \cdot v \cdot f + 0.033 \cdot v \cdot f + 19.517 \cdot f \cdot F + 0.363 \cdot v \cdot f \cdot F \]  
(3)
After substitution into equation (3) we can get the featuring points of the 3D diagram, which can be seen in Fig. 6. It demonstrates that in our experiments surface roughness of the workpiece is improving after burnishing when the value of ISq is greater than zero that is when its value is positive.

Figure 6 shows the top views and 3D surface roughness profiles of burnished surfaces of the workpiece after burnishing. Fig. 5a shows the results when burnishing force is F=45 N, while Fig. 5b relates to F=82 N.

3 CONCLUSIONS
On the base of Fig. 5 it can be conclude that the experimentally determined value of improvement ratio of surface roughness depended particularly on the extent of burnishing force and feed rate. The effect of increase of feed in case of smaller burnishing speed (45 m/min) is larger 12.57% than by application of larger (82 m/min) speed (11.62%) when smaller burnishing force (45N). With the application of larger burnishing force (82N) the improvement of surface roughness is 8.35% in case of smaller feed (0.05 mm/rev). In the case of the larger feed (0.1 mm/rev) the diminishing is 56.34%. Generally, in the case of smaller burnishing force the improvement of surface roughness is better than when larger force is applied.

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