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# Investigation of the influence of different burnishing parameters on shape correctness and residual stresses

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**Abstract**. Cold plastic procedures such as surface burnishing play an important role in life-enhancing machining methods. Application of this process the surface roughness improves, shape correctness also changes and the increases lifetime due to the compressive residual stress remains in subsurface are of the workpiece. This article deals with the change of these attributes and the correlation of these with the burnishing parameters: burnishing speed, feed rate, burnishing force and number of passes on diamond burnished low alloyed aluminium shafts. The experiments were executed by the Taguchi type full factorial experimental design method, the measurements of the cylindricity of the specimens were done with a circularity and position error machine while the measurement of residual stress was performed by X-ray diffraction method. The aim of this study is to define the appropriate range of technological parameters which result high improvements.

## 1. Introduction

In designing machining, it is increasingly common to choose methods for solving the manufacturing process by which the lifetime of the parts can be increased compared to the previous ones [1], while providing additional benefits as well [2]. Conventional machining processes such as milling and turning lead to a surface with inherent irregularities, while finishing processes such as grinding, lapping, polishing and honing commonly being employed to improve the surface finish. Unlike the above-mentioned traditional methods, which depend on chip removal, the burnishing process produces a smooth and work-hardened surface by plastic deformation of irregularities [1].

Burnishing differs from other cold-working surface treatment processes such as shot peening and sand blasting etc. produces a good surface finish, shape correctness and induces residual compressive stresses at the surface layers [4], thus quality of these layers has influence on fatigue life and work safety. The procedure of burnishing is performed for final finishing manufacturing of inner and outer cylindrical surfaces, the main areas of its applications are automotive and aeronautics industries.

The Taguchi type full factorial experimental design was used in this research [5-6], which is valid in between the minimum and maximum values of the input parameters. In the present experiments input parameters were: number of tool passes (i), feed (f), burnishing force (F) and burnishing speed ($v_b$), while the output parameters are: cylindricity (CYLt), tangential ($\sigma_t$) and axial ($\sigma_a$) residual stress.

## 2. Burnishing of outer cylindrical surfaces

Cold plastic processes, like burnishing, have always played an important role in industry and the first patent about this chipless procedure was published in the 1910s [7]. It has undergone tremendous progress over more than a century, adapting the ever-growing industrial and user needs.

Burnishing of outer cylindrical surfaces can be executed on conventional universal lathes or up-to-date CNC lathes.

In diamond burnishing the improving of shape correctness of the surface is caused by the interaction in between the tool - which material much harder than the workpiece - and the workpiece while performing rotational and linear movement with sliding friction between them [8]. The ball applies a normal force high enough to produce a plastic deformation on the surface which displaces the material from ridges to depressions on superficial micro-irregularities [9] (Fig.1.).

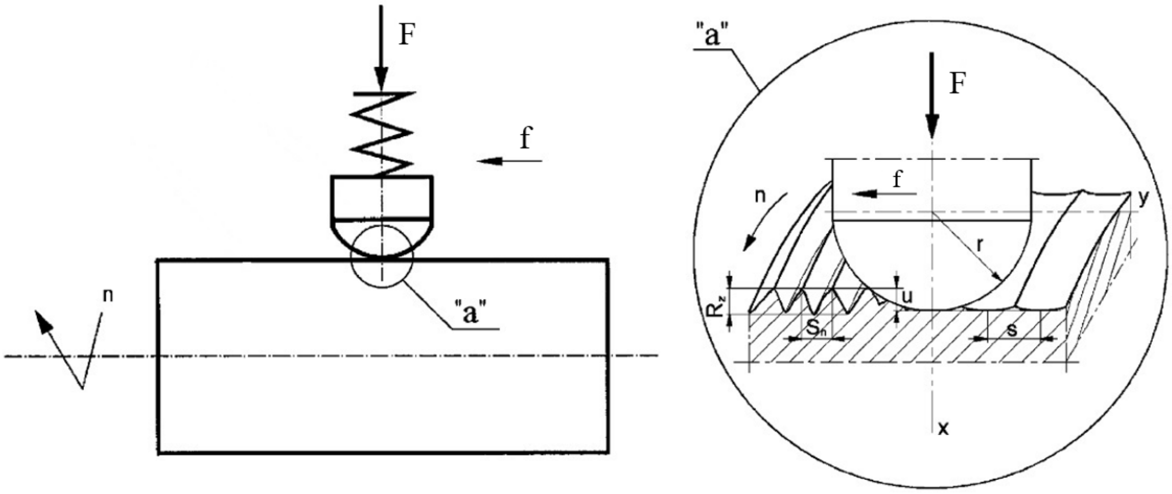


**Figure 1**. Schematic illustration of burnishing process [10]
F: burnishing force, n: workpiece rotational speed, f: feed, u: depth of tool penetration, Sn: spacing of irregularities of the treated surface, r: radius of the tool, Rz: previous surface roughness

This plastic deformation is realised in 0.01-0.2 mm thick layer in the subsurface of the workpiece because of the static contact shaping element (burnishing tool) and the outer surface of the workpiece [11-12].

## 3. Experimental conditions

### *3.1. Features of the investigated workpiece*

For this experiment we have chosen lightly alloyed aluminium material. The reason of the decision of the examination of aluminium was supported by the fact that automobile, aeronautics and astronautics industries more and more claims for the application of non-ferrous materials due to its low density and good mechanical properties [11].

**Table 1**. Chemical composition of the aluminium alloy

| Elements | Al | Si | Fe | Cu | Bi | Pb |
|---|---|---|---|---|---|---|
| Averaged wt% (weight percent) | 92.11 | 0.19 | 0.84 | 5.65 | 0.46 | 0.74 |

Fig. 2 shows the geometric design of the workpiece which is justified by the chosen experimental design method, it will be detailed in a later chapter and we considered the risk of bending during machining by examination of the so-called l/d relationship that is the proportion of the length and diameter of the piece. Based on these, the capture of the specimen was clamped into a three jaw chuck and supported by a tailstock.

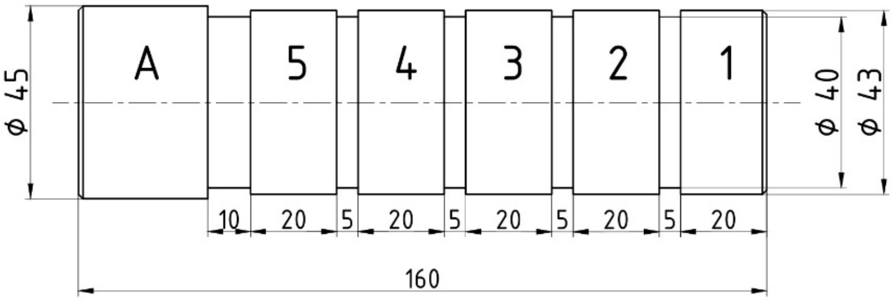


**Figure 2.** Geometrical dimensions of the workpiece

*3.2. The execution of the burnishing process*

During the experiments, a CNC lathe with flatbed by firm OPTIMUM type OPTIturn S600 was used which is in the workshop of Institute of Manufacturing Science at University of Miskolc. The tool tip was PCD (polycrystalline diamond) with 3.5 mm radius and the kinematic viscosity of the applied oil was 70 mm2/s. Fig. 3 shows the process in progress.

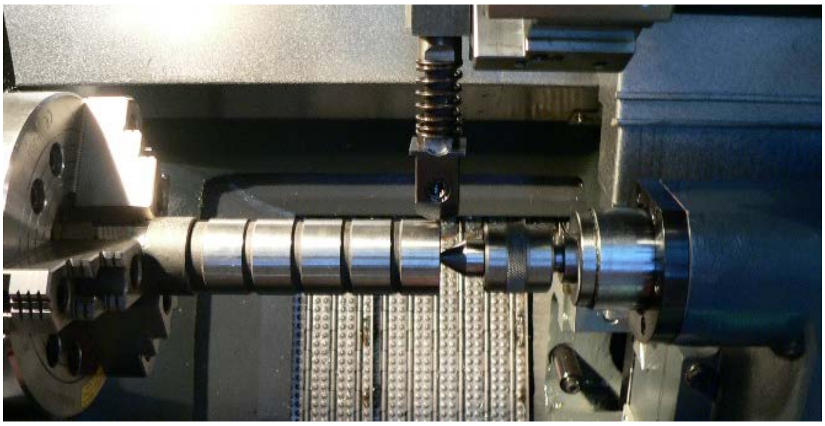

**Figure 3.** The burnishing process

The following burnishing parameters were examined: number of tool passes, feed rate, burnishing force and speed, all of it have a lower and a higher value according to the matrix of the Taguchi type Full Factorial Experimental Design can be seen on Table 2, which contains the burnishing parameters in natural dimensions and their transformed values.

**Table 2.** The applied burnishing parameters

| Sign of specimen | Parameters of burnishing | | | Transformed parameters | | |
|---|---|---|---|---|---|---|
| | i [ø] | f [mm/rev] | F[N] | $x_1$ | $x_2$ | $x_3$ |
| 1 | 1 | 0.001 | 10 | -1 | -1 | -1 |
| 2 | 3 | 0.001 | 10 | +1 | -1 | -1 |
| 3 | 1 | 0.005 | 10 | -1 | +1 | -1 |
| 4 | 3 | 0.005 | 10 | +1 | +1 | -1 |
| 5 | 1 | 0.001 | 20 | -1 | -1 | +1 |
| 6 | 3 | 0.001 | 20 | +1 | -1 | +1 |
| 7 | 1 | 0.005 | 20 | -1 | +1 | +1 |
| 8 | 3 | 0.005 | 20 | +1 | +1 | +1 |

### *3.3. Measuring of the cylindricity*

Measurement of the cylindricity was done with a circularity and position error measuring machine type Talyrond 365 [14]. In this investigation an inductive sensor was applied for measuring before and after burnishing in 2 mm distance.

In all 16 cylindricity indices was analysed and one of them was chosen and examined which mostly determines operating properties. This is the so called CYLt which shows the total distance between peaks (CYLp) and valleys (CYLv) according to a reference cylinder (Fig. 4) [15].

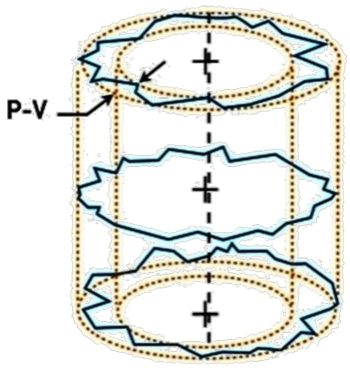


**Figure 4.** Cylindricity parameters: CYLp, CYLv and CYLt

### *3.4. Measuring of the residual stress*

Residual stress is a process-induced stress, frozen in a moulded part, that exists in a body in the absence of external loading or thermal gradients. In a structural material or component, residual stresses exist in the object without the application of services or other external loads. They affect a part similarly to externally applied stresses.

In materials due to their macroscopic residual stress the atomic cores in the lattice points are put of their balance. In the point of view of crystallography, it means that the parameters of the lattice do changes. Distance between lattice planes are changed because of the residual stress, these distances can be measured, so the values of the stress can be calculated from them [16].

So, during measuring of residual stress, the wave-length of the X-ray is known, and the dislocation of the Bragg-angle is measured. The dislocation has been caused by the changing of lattice planar distances. The formula (1) was applied what is called Bragg-equation [17]:

$$n\lambda=2d_{hkl}\sin\Theta, \qquad (1)$$

where:

| | |
|---|---|
| n: | integer determined by order given |
| λ: | wave-length of X-ray |
| dhkl: | spacing between the planes in the atomic lattice |
| Θ: | angle between the incident ray and the scattering planes |

Residual stress distributions in cold formed sections are dependent primarily on the plastic deformation in the manufacturing process. Thus, it is necessary to know the manufacturing process before measuring the residual stress. These methods can be classified into three types including destructive, non-destructive and semi-destructive one [18].

In this investigation the measuring process was executed with an X-ray diffraction measuring machine type Stresstech Xstress 3000 G3R, which realizes non-destruction test and complex shapes can be measured providing rotation of the measuring head is not restricted. Fig. 5 illustrates the basic principles of the described method.

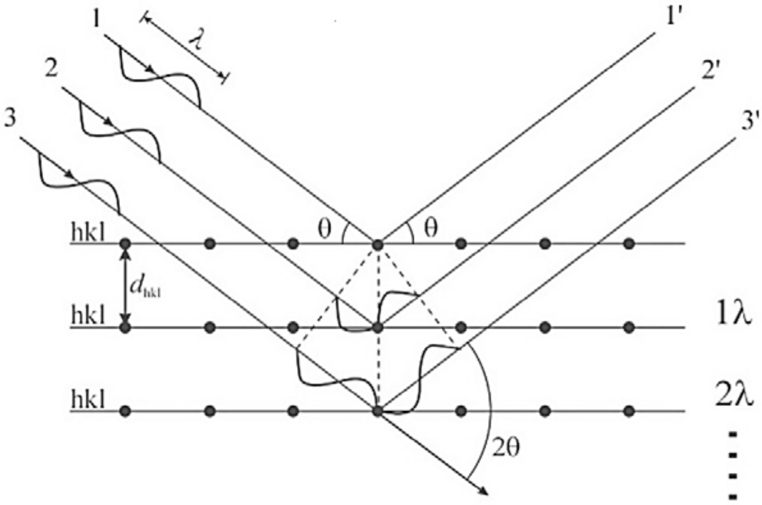


**Figure 5.** The X-ray principle

Measuring was done on 3 points at 60° in tangential and axial direction too because it was supposed that the direction of the processing has influence on the changing of the stress condition.

## 4. Results and evaluations

For evaluation of measured data improvement ratios were introduced, which are shown in formula (2) and (3):

$$\rho_{\sigma/CYLt} = \frac{|x_b|}{|x_t|} \qquad (2)$$

$$\rho\% = (\rho - 1) \cdot 100\%, \qquad (3)$$

where: $\rho_\sigma$ Improvement ratios of residual stresses (σ) and cylindricity (CYLt). This is a dimensionless ratio, which textures the changes occurring because of manufacturing,
$x_t$ Residual stress and cylindricity remain after turning,
$x_b$ Residual stress and cylindricity remain after burnishing,
ρ% The percentage value of the improvement ratio.

The higher the value of $\rho_\sigma$, the greater the improvement due to burnishing, while in the point of view of cylindricity ($\rho_{CYLt}$), the smallest values of the ratios mean positive effect.

The measured data and the calculated improvement ratios are summarized in Table 3.

**Table 3.** Measured values and calculated improvement ratios

| Sign of spec. | $\sigma_t$ [MPa] | | $\rho_{\sigma t}$ [%] | $\sigma_a$ [MPa] | | $\rho_{\sigma a}$ [%] | CYLt [µm] | | $\rho_{CYLt}$ [%] |
|---|---|---|---|---|---|---|---|---|---|
| | turned | burnished | | turned | burnished | | turned | burnished | |
| 1 | -9.5 | -187.0 | 1868 | 74.5 | -217.0 | 391.3 | 14.32 | 14.69 | 2.583 |
| 2 | -9.5 | -142.3 | 1397 | 74.5 | -202.7 | 372.1 | 13.04 | 173.99 | 1234 |
| 3 | -9.5 | -194.1 | 1943 | 74.5 | -300.3 | 503.1 | 15.83 | 13.01 | -17.81 |
| 4 | -9.5 | -183.5 | 1831 | 74.5 | -307.9 | 513.3 | 13.2 | 24.11 | 82.65 |
| 5 | -9.5 | -152.8 | 1508 | 74.5 | -212.9 | 385.8 | 18.88 | 64.6 | 242.2 |
| 6 | -18.5 | -115.1 | 522.2 | 67.0 | -167.1 | 349.4 | 16.41 | 201.54 | 1128 |
| 7 | -18.5 | -198.7 | 974.1 | 67.0 | -308.9 | 561 | 12.36 | 23.7 | 91.75 |
| 8 | -18.5 | -132.5 | 616.2 | 67.0 | -198.9 | 396.9 | 14.96 | 76.62 | 412.2 |

Application of Factorial Experiment Design method empirical formulas (4-6) were created from the calculated values. Calculations and axonometric figures (Fig. 6-8) were prepared using „Mathcad 16.0" software.

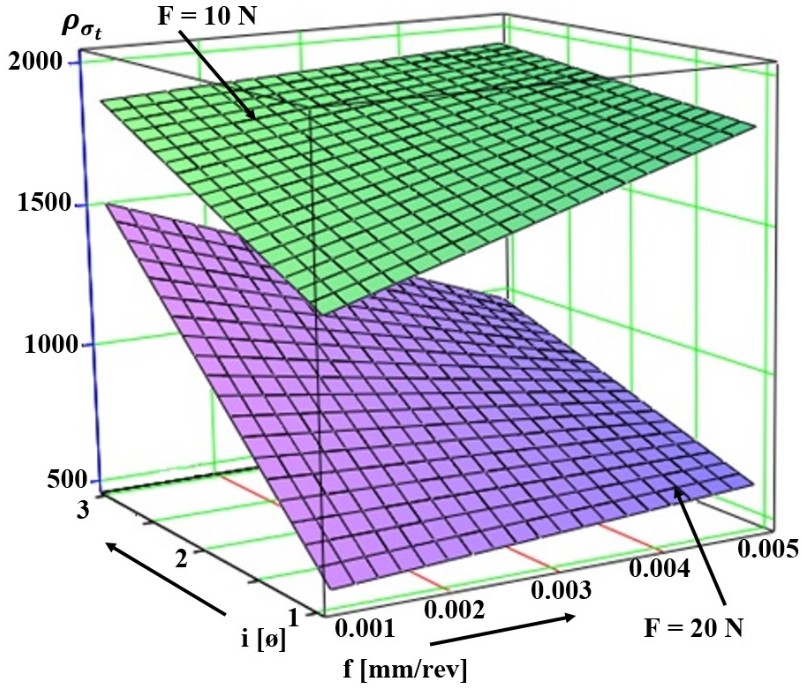


**Figure 6.** Changing of improvement ratio of tangential residual stress

$$\rho_{\sigma_t} = 2.0463 \cdot 10^3 + 10.637 \cdot i + 1.597 \cdot 10^5 \cdot f + 8.324 \cdot F + 1.126 \cdot 10^4 \cdot i \cdot f - 29.101 \cdot i \cdot F - \\ -1.858 \cdot 10^4 \cdot f \cdot F + 3.361 \cdot i \cdot f \cdot F \quad (4)$$

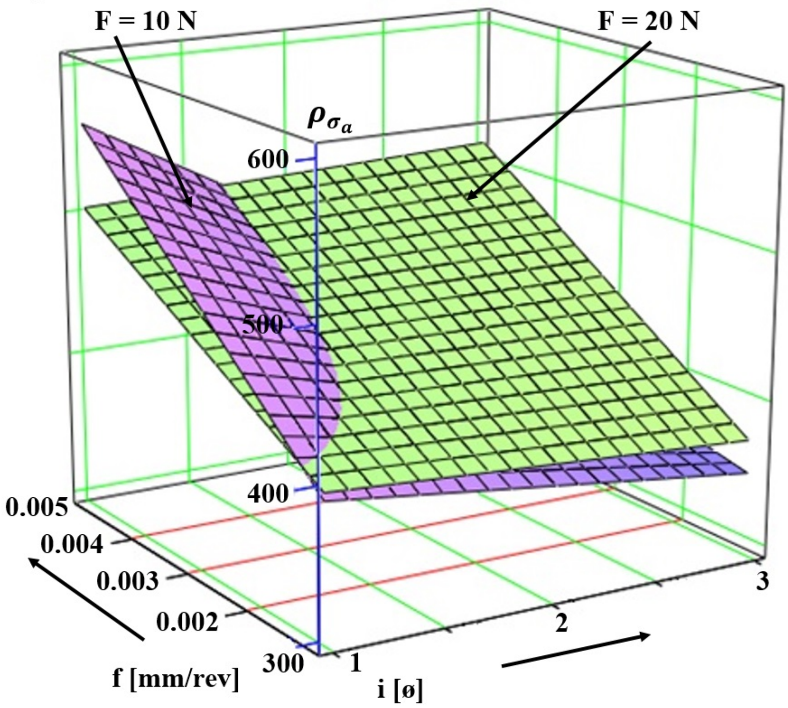


**Figure 7.** Changing of improvement ratio of axial residual stress

$$\rho_{\sigma_a} = 409.0125 - 24.312 \cdot i - 1.121 \cdot 10^4 \cdot f - 3.239 \cdot F + 2.331 \cdot 10^4 \cdot i \cdot f + 1.104 \cdot i \cdot F + \\ +3.549 \cdot 10^3 \cdot f \cdot F - 1.964 \cdot 10^3 \cdot i \cdot f \cdot F \quad (5)$$

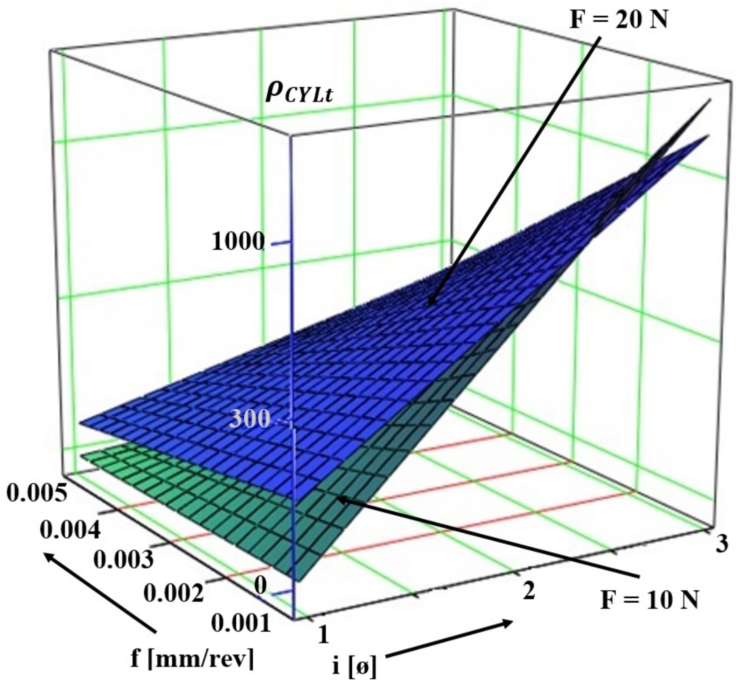


**Figure 8.** Changing of improvement ratio of CYLt cylindricity parameter

$$\rho_{\sigma_{CYLt}} = -1.265 \cdot 10^3 + 1.001 \cdot 10^3 \cdot i + 2.395 \cdot 10^5 \cdot f + 51.564 \cdot F - 2.121 \cdot 10^5 \cdot i \cdot f - 24.351 \cdot i \cdot F - \\ -1.032 \cdot 10^4 \cdot f \cdot F + 7.07 \cdot 10^3 \cdot i \cdot f \cdot F \quad (6)$$

## 5. Summary

Following statements can be asserted on the base of executed and evaluated experiments:

- In tangential direction, perpendicular to the direction of manufacturing, the value of the improvement ratios of residual stresses were the highest, $\rho_{\sigma t}$ = 1943 %, when the burnishing parameters were: f = 0.005 mm/rev; and F = 10 N and single number of passes (i = 1). Using these burnishing parameters, in axial direction the maximum value of the improvement ratio of residual stresses is $\rho_{\sigma a}$ = 503 %.
- While the residual stresses (both in tangential and axial direction) were and greatly improved due to the burnishing process, in cylindricity in only one workpiece surface point of view was experienced a beneficial change signed "3", in which the most favourable tangential residual stress value was measured too.
- Examining the evaluated results can be stated that applying the smaller burnishing force with single number of passes is more positive, while feed rate has not considerable effect to the improvement ratios in these burnishing parameter ranges.

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