MODELLING OF THE IMPACT OF BURNISHING FORCE ON AVERAGE SURFACE ROUGHNESS

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Abstract
As a result of the development of engineering technology, new opportunities and methods are constantly being developed to examine individual material structure changes, but most of these are impossible to implement on a low budget. Tests carried out with finite element simulations enable the optimization of machining processes and the reduction of experimental costs. The paper discusses the modelling of burnishing process that can effectively reduce surface roughness and the effect of burnishing force on average surface roughness. The machining is simulated using DEFORM-2D software, corresponding to the values of the experimental parameters (burnishing force, feed, speed) implemented in practice, allowing a comparative analysis of the material quality of low alloyed aluminium.

Keywords: *burnishing, finite element modelling, average surface roughness, DEFORM-2D*

1. Introduction

The main aim of modern plastic forming is to produce the shape and size of the designed part - in addition to ensuring the appropriate values of the stiffness and deformation characteristics - in such a way that the subsequent machining is minimized or unnecessary (Tisza et al., 2007), thus reducing the environmental pollution the amount of cooling and lubricating fluid can be reduced, and machining with a low environmental impact can be realized. One of these processes is the diamond surface burnishing, the application of which, and the effect of certain parameters to be set on surface roughness, has been studied experimentally by several researchers.

To study the mechanism of plastic deformation during burnishing Salashoor et al. (Salashoor et al., 2018) created a 2D-FEM model of burnishing of Mg-Ca0.8 biomaterial using ABAQUS software, but only the tool indentation was simulated without any associated movements. Posdzich et al. have already created a more complete 2D model (Posdzich et al., 2018) to presentation and interpretation of the relationships between the surface structure before and after the burnishing process and the effect of the burnishing force. According to the results of their numerical analysis the direction of the burnishing feed and surface structure of the pre-machined workpiece (surface before burnishing) have no relevant impact on the burnishing process. In contrast, Stalin John et al. took the roughness of the pre-burnishing operation to such an extent that it was also used in their finite element simulation in DEFORM-2D software. Due to this, the maximum and the minimum deviation between the experimental and simulation values of surface roughness were 3.22% and 8.69% (Stalin John et al., 2016). Saldana-Robles and his colleagues also considered it important to take into consideration the quality of the surface to be burnished, because different processes create surface irregularities with different patterns and amplitudes and taking them into account is necessary to create a properly applicable finite element model. In an unusual way, in their investigation the FEM model of burnishing process was developed with random roughness and that was used to predict residual stress and surface roughness after burnishing (Saldana-Robles et al., 2015).

Randjelovic et al. approached the examination of the burnishing process on aluminium alloy from a theoretical point of view, using numerical simulation according to the results of which they found that the surface roughness can be reduced most effectively if the penetration depth of the tool reaches the height of the maximum roughness peak “Rp” (Randjelovic et al., 2015).

In their experiment on aluminium alloy, Yu and Wang took into account the effect of the stiffness of the spring in the tool, as well as the penetration depth of the tool head, in addition to the burnishing feed and speed. In the case of these two latter characteristics, the use of higher rates has led to more favourable results (Yu and Wang, 1999). According to Hassan and Al-Bsharat's experimental results on a non-metallic material, the surface roughness improves as a result of burnishing if we increase the value of the feed, force, speed and number of passes, but only up to a certain value, an optimum point, after which deterioration is observed (Hassan and Al-Bsharat, 1996).

Several research studies have also analysed the changes of residual stress station, for example Charfeddine et al. combined a thermomechanical process, grinding with the ball burnishing process. In their investigation the surface and subsurface behaviour was examined with 3D FEM ABAQUS model. Based on its results, they determined that the increase of burnishing force increases the compressive residual stress and ensures obtaining a deeper compressive layer (Charfeddine et al., 2021). Sztankovics and Varga also showed an application of Finite Element modelling in their study, where they analysed some aspects of the burnishing process with the ThirdWave Advantedge 7.601 software. It is showed that the increase of the burnishing force has the highest effect, followed by the feed and surface speed (Sztankovics and Varga, 2022).

Considering the above-mentioned literature, among the many factors affecting surface quality, in the article I deal with the simulation of the effect of the burnishing force on the average surface roughness.

2. Surface treatment with burnishing

When burnishing external cylindrical surfaces, the plastic deformation occurs because of the interaction during the sliding friction created by the static contact of the tool and the workpiece. During machining, no chips, sparks, or dust are produced, and the need for cooling and lubrication is minimal, and in some cases can even be eliminated, so we can realize environmentally friendly and cost-effective machining at the same time (Skoczylas and Zaleski, 2020; Saldana-Robles et al., 2018; Balland et al., 2013).

It is used as a high-precision, low-roughness finishing operation that can be implemented on universal and more modern NC-CNC lathes as well, the great advantage of the latter being that individual machining parameters can be set numerically. During the application of the process, the reduction in surface roughness, the improvement in shape correctness and the hardening phenomena are the result of the interaction between the surface of the workpiece and the tool, which is much harder than the material to be machined (Bálint and Gribovszki, 1975; Luo et al., 2005; Korzynski, 2007), as it is illustrated in Figure 1.

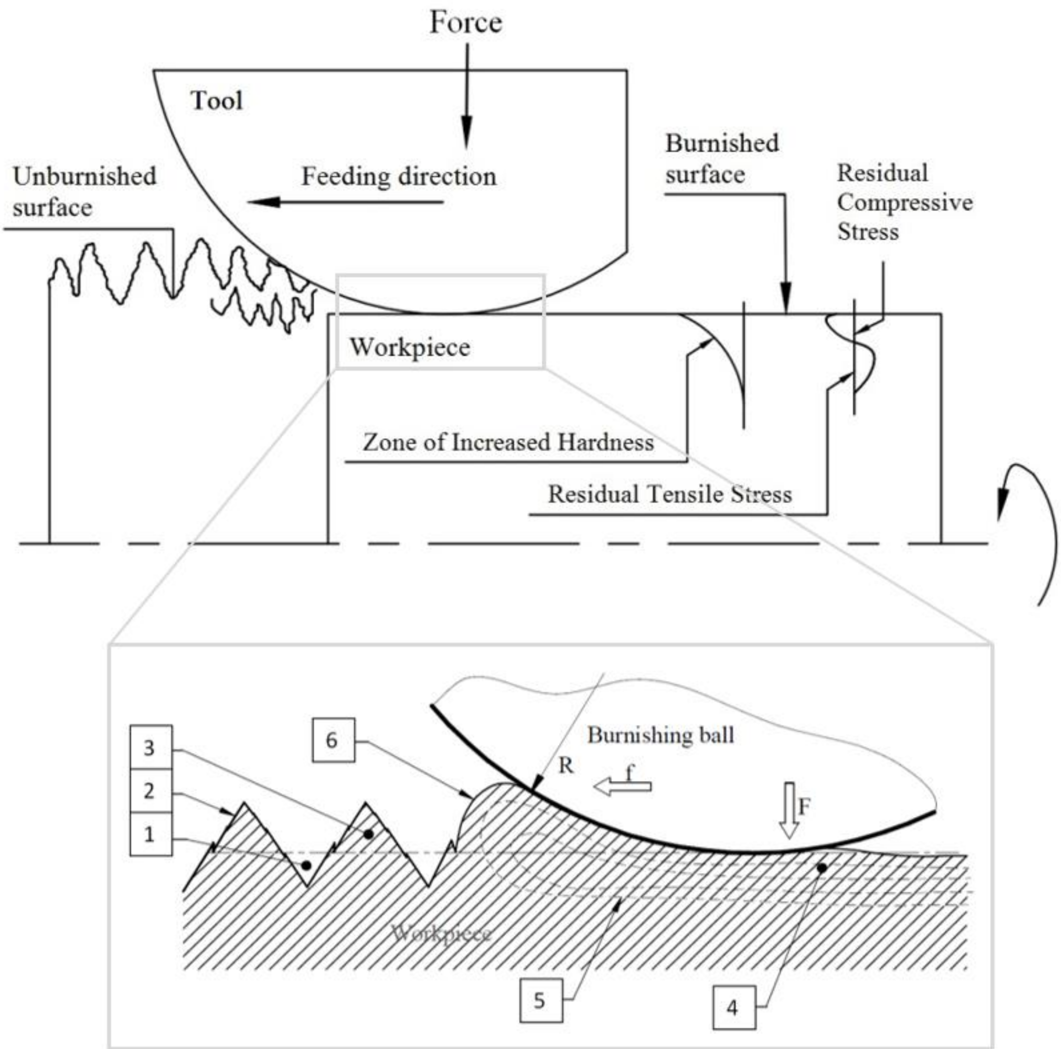

Figure 1. *Schematic illustration of burnishing process (Vereschaka, 2013; Dzionk et al., 2019).*

1 – valley of roughness, 2 – surface profile, 3 - peak of roughness, 4 – zone of material deformation, 5 – zone of plastic and elastic deformation, 6 – wave of material in front of the burnishing tool

The range of this deformation, as the hardening layer of the material is quite high and changes in the structure of the surface layer occur at a significant depth.

The experimental work was realized on a CNC lathe machine type OPTIMUM OPTIturn L-Series 440 at the Institute of Manufacturing Science. A PCD spherical (R = 3.5 mm) burnishing tool was used with a manual feed small amount of lubricating oil. Table 1. contains the set parameters of the process, the numerical determination of these were based on preliminary experiments and extensive literature review.

Table1. *Burnishing parameters*

Parameters of burnishing	Value	Unit
Burnishing force (F)	10/20	N
Feed rate (f)	0.001	mm/rev
Burnishing speed (v_c)	15	m/min

The burnishing force perpendicular to the surface of the workpiece is adjusted using the spring built into the tool, based on spring force diagram, since according to Hooke's law which is valid for linear springs, the elongation is directly proportional to the load (Kozák and Szeidl, 2012).

3. Application of the finite element method

Examining how the change of individual burnishing parameters affect the change in surface roughness is an extremely time-consuming process. This is the reason why the relationship between burnishing force and surface roughness was studied in virtual space in this publication, thereby saving time and costs.

The finite element simulations were made in DEFORM software, through an axisymmetric problem in 2D, assuming planar deformation thus, the surface of the tool in contact with the workpiece is simplified to a semicircle. I aimed for the closest simulation to reality, so I imported the topography of a real turned surface into the software, the initial surface roughness of which was 1.478 µm.

The high-hardness PCD tool does not change shape during burnishing, so it was defined as a rigid body, while the workpiece was assumed as an elastoplastic body. In finite element simulations the implementation of the relevant mesh is a critical issue moreover in this case when careful attention had to be paid to ensure that meshing will not change the original surface roughness. Thus, square elements with a side length of 0.01 mm were used at the subsurface area. After meshing the surface roughness changed from the physically measured from 1.478 µm to 1.457 µm. With an even smaller side length of the mesh, the surface roughness can be more correctly following, but in this case the calculation time would significantly increase. Figure 2 shows a section of the tool and the meshed workpiece.

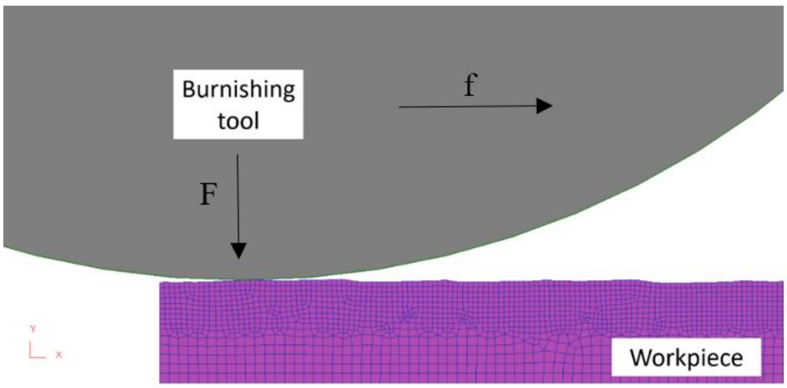

Figure 2. *A section of the FEM model.*

For describe the formability of the workpiece made of 6065 high strength aluminium in T0 condition, the mechanical properties of it need to be specified. The elastic behaviour of the material was specified with the Young modulus (68900 MPa) and a Poisson's ration (0.33).

During burnishing the surface roughness of the workpiece is reduced by plastic forming. As a result of the burnishing force small plastic deformations are created on and near the surface of the workpiece. To describe these small deformations, the points of the flow curve taken experimentally must be approximated by a function in the finite element space. The DEFORM FE code provides different methods to define the flow stress changing along deformation. In this paper the so called "power law" relationship was used which can be described by the following equation:

$$\bar{\sigma} = c\bar{\varepsilon}^{n}\dot{\bar{\varepsilon}}^{m} + y, \qquad (1)$$

where:

$\bar{\sigma}$	flow stress,	
c	material constant,	c = 121.228
$\bar{\varepsilon}$	effective plastic strain,	
$\dot{\bar{\varepsilon}}$	effective strain rate,	
n	strain exponent,	n = 0.266076
m	strain rate exponent,	m = 1.12487
y	initial yield stress	y = 50.0003 MPa

After determining the geometries and behaviour of the material, the contact between the tool and the workpiece and boundary conditions had to be specified. In addition to the exerted force, the tool creates the plastic forming with a relative displacement compared to the surface of the workpiece. In the simulation, the displacement speed was the same as the real feed rate, and the friction between the surfaces was neglected as lubrication was used during the physical experiments. The purpose of the tests was to examine the change in surface roughness created by changing the burnishing force. Accordingly, I prepared simulations between 5...20 N with a division of 2.5 N, which were validated for burnishing forces of 10 and 20 N. Figure 3 illustrates the deformation that occurs in the initial step of burnishing under the influence of these two forces.

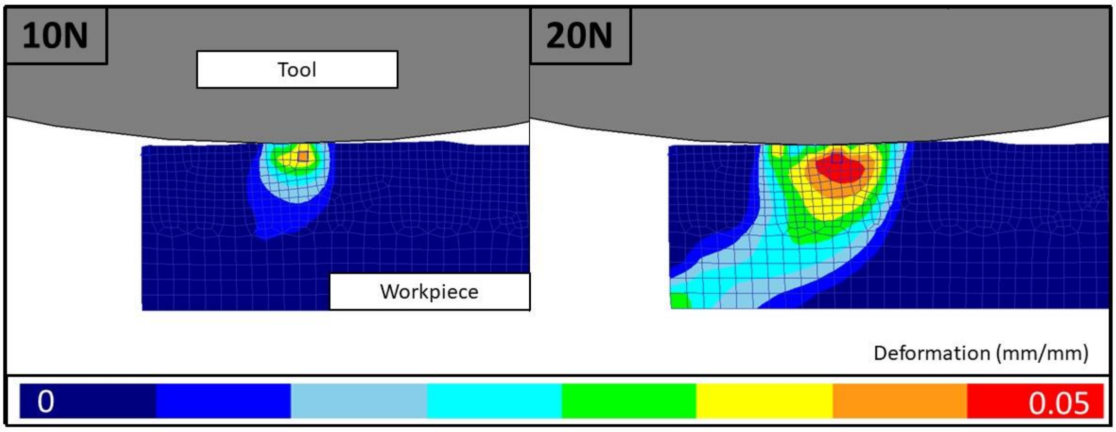

Figure 3. *The deformation produced by the burnishing force at the beginning of machining.*

4. Results

From the model I exported the height points of the workpiece surface that were modified due to the application of the procedure, so the roughness profiles could be drawn, based on which the average surface roughness was numerically determined. These roughness results - obtained after running the finite element model - are summarized in Table 2 which can be compared with the practically realized machining when setting 10 N and 20 N. These results are illustrated in Figure 4 as well.

Table 2. *Results of the average surface roughness (Ra)*

R_a [μm]							
F [N]	**5**	**7.5**	**10**	**12.5**	**15**	**17.5**	**20**
FEM	1.177	0.0964	0.0819	0.0682	0.0574	0.0468	0.0388
Experiment			0.0965				0.0367

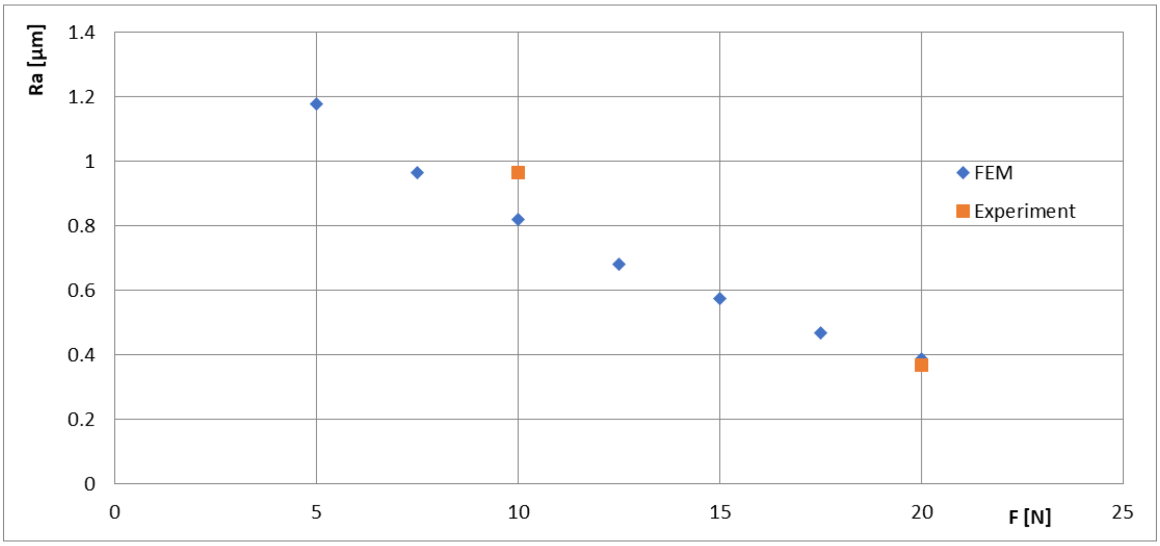

Figure 4. *Impact of the burnishing force on average surface roughness.*

5. Summary

The study dealt with the analysis of the changing of surface roughness caused by diamond tool burnishing process and its FEM simulation, highlighting the effect of the burnishing force. Based on the simulation model and evaluating the numerical results, the following can be concluded:

- The average surface roughness rate decreases in direct proportion to the increase of the burnishing force during the burnishing of low alloyed aluminium, while keeping the other parameters constant,
- The simulation model fits to the measurement results of the real experiment with reasonable accuracy; the difference is 16 % for 10 N and only 6 % for 20 N,

- Thus, the created model can be effectively used for carry out further tests.

The undertaken numerical studies will be continued, in the future I would like to examine and simulate the changing of stress conditions caused by burnishing process.

6. Acknowledgement

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