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FEM ANALYSIS OF THE BURNISHING PROCESS OF X5CrNi18-10 STAINLESS STEEL

Abstract. *The burnishing process can improve the surface roughness of machined parts, while having an advantageous effect on the properties of the layer below the surface. In this paper the effect of the surface speed, the feed rate and pressing force are analysed with Finite Element Method. The affected width and depth were analysed during one pass of the burnishing tool. We also examined the highest pressure and the stress distribution of the surface layer. The values of the studied parameters were chosen according to the "Design of Experiments" method. Equations determining the studied properties were also given.*

Keywords: *burnishing; design of experiments; FEM simulation.*

1. INTRODUCTION

In the development of different manufacturing processes and systems, many factors must be considered. An aim of these improvements is the increase the quality of the machined surface while decreasing the costs of manufacturing [1]. However, production engineers must consider the energy efficiency and environmental impact of different procedures during the process planning. A further aim is to improve the properties of workpieces to reduce the weight and therefor the fuel consumption [2]. The burnishing process can effectively improve the properties of the surface layer.

Diamond burnishing leads to a favourable combination of the 3D height and shape parameters for surface texture in the point of view of the wear resistance enhancement [3]. Raza et al. showed in their review work that the burnishing parameters such as force, feed, speed, number of tool passes, ball diameter and lubrication medium have a greater influence on the surface characteristics of the component [4]. The experimental results of Mohamed et al. indicate that feed, speed, burnishing force and number of passes are the most important and significant parameters to improve hardness [5]. Fedorovich et al. showed in their study that the optimal choice of the technological parameters should consider both the equivalent stress distribution in the surface layer of the products and the factors influencing the tool wear observed under a particular processing mode [6]. An effective way of increasing the depth of the hardened layer is the increase of the number of passes [7]. Yaman et al. studied the surface integrity alteration and found that the burnishing force and burnishing speed are critical parameters to make the burnishing process more effective and increase the wear resistance of parts [8]. Teimouri et al. proved in their theoretical and experimental work, that among the process factors the burnishing depth has the greatest influence on microhardness alternation [9]. The analysis of Barahate et al. showed that the burnishing feed rate has the highest impact on the surface roughness (a contribution of 54.51% in their experiments), followed by load and burnishing speed [10]. Borysenko et al. studied the burnished surface on reverse engineering approach, where the models of the workpiece and the tool were created using 3D scanning [11]. Ferencsik et al. studied the burnishing process by the application of FEM simulation, and showed that numerical value of roughness is in a good correlation with the experimental results [12].

The values of the affected depth and width in burnishing of different materials are essential information in the process planning of the procedure. Therefore, the alteration effect of the feed, surface speed and pressure force were studied in diamond burnishing using Finite Element Method simulations in this paper. The results were evaluated using the Design of Experiment method.

2. EXPERIMENTAL METHODS AND CONDITIONS

In this paper we intended to make a study to better describe and understand the processes in the surface layer during burnishing. The aim of our study is the description of the affected depth and width in diamond burnishing by FEM analysis. The finite element simulations were done with the ThirdWave Advantedge 7.601 software.

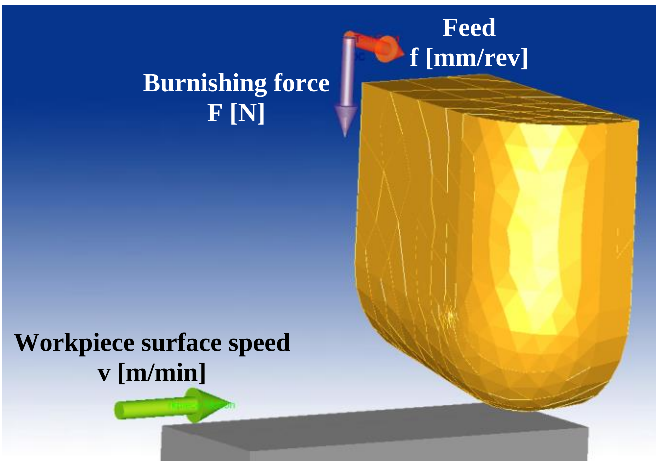


Figure 1 – Experimental setup in the FEM software

The setup of the tool, workpiece, burnishing force, feed and surface speed were shown in Figure 1. It can be seen that the burnishing of a shaft is simulated on a plane. The burnishing force were adjusted by the precise adjustment of the depth of cut parameter, where the chip removal is not occurred, and the desired load could be measured from the force perpendicular of the workpiece surface. X5CrNi18-10 grade stainless steel were selected as workpiece material. The tool material was PCD with medium conductivity. The initial temperature was 20 °C. Furthermore, minimum element size of 0.0054 mm, refined region radius of 0.026 mm, refining factor of 4, coarsening factor of 3, 6.0 grading near the cutting edge were set.

Three process parameters were analysed in our study: surface speed (*v*), feed (*f*), burnishing force *(F*). The values of these parameters were chosen according to the Full Factorial Design of Experiments method, where a high (+1) and a low (-1) value is determined for each factor, and the experimental setup is generated through the combination of these values. Table 1 shows the experimental plan for the 8 cases. The parameters were chosen according to our real experimental plan of burnishing a shaft with 50 mm diameter.

We measured 4 parameters in each setup. The first is the stress depth, which represents the depth where at least 350 MPa Mises stress occurs, which is the 1.5-fold value of the materials proof strength. The second is the Burnished depth, which measures the affected depth according to the perpendicular stress (Stress Y-Y in the program notation). The third is the Burnished width, which measures the affected width according to the shear stress (Stress Y-Z in the program notation). The final studied parameter is the maximum value of the Pressure occurring in the surface layer during burnishing.

Table 1 – Setup values of the studied process parameters

	v	*f*	*F*	*n* [1/min]	*v* [m/min]	*f* [mm/rev]	*F* [N]
1	-1	-1	-1	265	41.17	0.025	30
2	1	-1	-1	375	58.26	0.025	30
3	-1	1	-1	265	41.17	0.05	30
4	1	1	-1	375	58.26	0.05	30
5	-1	-1	1	265	41.17	0.025	40
6	1	-1	1	375	58.26	0.025	40
7	-1	1	1	265	41.17	0.05	40
8	1	1	1	375	58.26	0.05	40

3. EXPERIMENTAL RESULTS

Measurements were made on the results of the FEM simulations according to the previous conditions. Here an example is given for the better understanding of the process in case of Setup 8. The results of the measurements were shown in Table 2.

Figure 2 shows the measurement of the stress depth and burnished depth. In the former, the highest distance from the surface was taken where the Mises stress value exceeds 350 MPa, which is crucial for the elastic deformation. In the latter the highest distance of that FEM element was measured, where the perpendicular stress is different than 0.

Table 2 – Results of the FEM simulations

	Stress Depth [mm]	Burnished Depth [mm]	Burnished Width [mm]	Pressure [MPa]
1	0.0834	0.2007	0.1145	1367.37
2	0.0907	0.2061	0.1266	1321.92
3	0.1057	0.1843	0.1379	1412.23
4	0.1349	0.2249	0.1604	1372.58
5	0.0913	0.2178	0.1092	1625.49
6	0.1177	0.1835	0.1123	1672.84
7	0.1141	0.2978	0.1810	1652.82
8	0.1412	0.2960	0.2115	1612.35

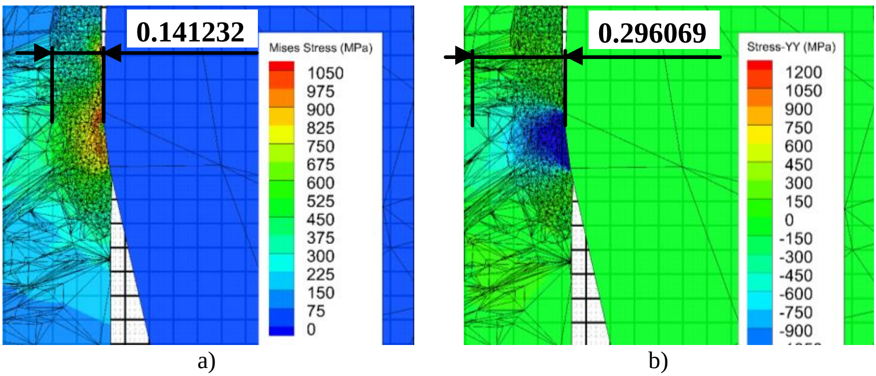
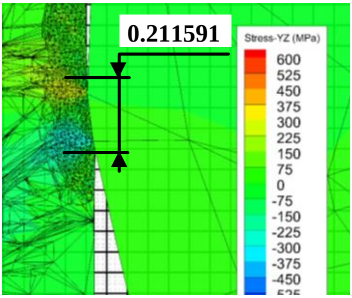
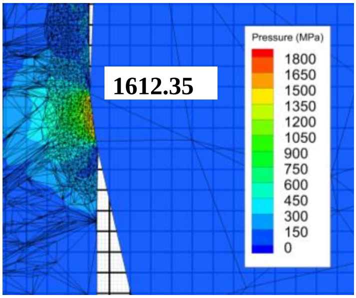


Figure 2 – Measurement of the Stress depth (a) and Burnished depth (b), Setup 8



a)



b)

Figure 3 – Measurement of the Burnished width (a) and Pressure (b), Setup 8

The measurement of burnished width and pressure can be seen in Figure 3. To measure the affected width, we measured the distance between the occurring shear stresses. The highest value of the pressure occurring in the surface layer was provided by the FEM software.

A further aim of our study was to provide equations for the calculation of the studied attributes. These were determined in the form of Equation 1, where the k_i are the constant of the different factors.

$$y(v,f,F) = k_0 + k_1 v + k_2 f + k_3 F + k_{12} vf + k_{13} vF + k_{23} fF + k_{123} vfF \quad (1)$$

The k_i constants were determined for the studied parameters. The results can be seen for the Stress depth (y_1) in Equation 2, for the Burnished depth (y_2) in Equation 3, for the Burnished width (y_3) in Equation 4 and for the Pressure (y_4) in Equation 5.

$$y_1(v,f,F) = 0.3641 - 7.912 \cdot 10^{-3} v - 7.369 f - 8.933 \cdot 10^{-3} F + 0.2 vf + 2.354 \cdot 10^{-4} vF + 0.205 fF - 4.948 \cdot 10^{-3} vfF \quad (2)$$

$$y_2(v,f,F) = 0.2586 - 4.772 \cdot 10^{-3} v - 16.39 f - 1.006 \cdot 10^{-3} F + 0.101 vf - 2.171 \cdot 10^{-4} vF + 0.4110 fF - 6.258 \cdot 10^{-4} vfF \quad (3)$$

$$y_3(v,f,F) = 0.0609 - 4.644 \cdot 10^{-3} v - 0.991 f - 8.763 \cdot 10^{-4} F + 0.094 vf - 1.517 \cdot 10^{-4} vF + 0.031 fF \quad (4)$$

$$-3.963 \cdot 10^{-3} vfF$$

$$y_4(v,f,F) = 1.966 - 35.722v - 2.373 \cdot 10^4 f - 17.345F + 670.927vf - 1.091vF + 832.037fF - 21.912vfF \quad (5)$$

4. DISCUSSION

Equation 2-5 were drawn as a function of the surface speed (*v*) and feed (*f*) for the two levels of the burnishing force.

Figure 4 shows the effect of these parameters on the Stress depth and Burnished depth. We conclude that the increase of the perpendicular force has an increasing effect on these parameters, however a larger increase can be seen in the affected depth than the stress depth. Increasing the surface speed led to an interesting finding. While the 1.5-fold increase of the speed led to an average of 1.2-fold increase in the stress depth, the affected depth remained the same. Doubling the feed leads to an average 1.25 increase in the stress depth, while the affected depth only increases in the higher load setups, and it remains nearly the same if the burnishing force was adjusted to 30 *N*.

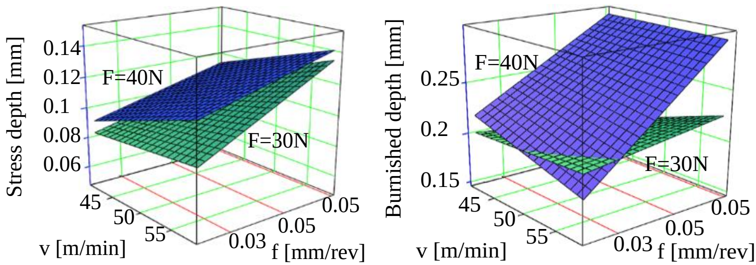


Figure 4 – Stress depth and burnished depth as a function of the studied parameters

The alteration of the burnished width and the pressure is presented in Figure 5.. The alteration of the surface speed has a very low effect on these parameters (0-16% change). However increasing the feed has a significant impact on the affected width. By the 1.5-fold incrase of the feed, a 1.2-1.8-fold increase can be observed in the affected width. The effect of burnishing force alteration depends on the feed value. As expected, the highest pressure value increases by the increase of the burnishing force: 1.33-fold increase of the latter leads to an 1.2 higher pressure on avarage. The surface speed and the feed has almost no effect on this studied parameter.

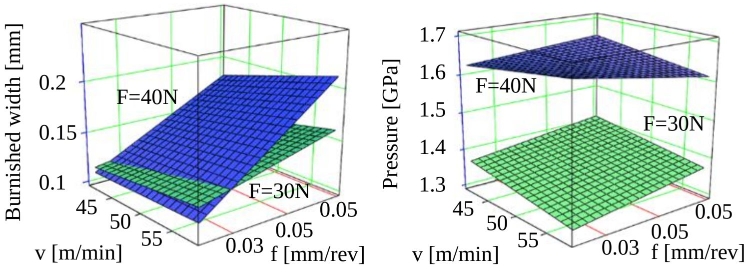


Figure 5 – Burnished width and pressure as a function of the studied parameters

SUMMARY

The burnishing process of X5CrNi18-10 grade stainless steel material was studied in this paper by the application of FEM simulations. The analysed parameters were selected according to the Design of Experiments method. The stress depth, the affected depth and width and the pressure were measured and further analysed. Equations were given for the calculation of these parameters in the studied range. The effect of the surface speed, feed and burnishing force were analysed. It is found that the increase of the burnishing force has the highest effect, followed by the feed.

ACKNOWLEDGEMENTS

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АНАЛІЗ ПРОЦЕСУ ВИГЛАДЖУВАННЯ НЕРЖАВІЮЧОЇ СТАЛІ X5CrNi18-10 МЕТОДОМ КІНЦЕВИХ ЕЛЕМЕНТІВ

Анотація. *Алмазне вигладжування призводить до сприятливого поєднання тривимірних параметрів висоти та форми текстури поверхні з точки зору підвищення зносостійкості. Значення порушеної глибини та ширини при вигладжуванні різних матеріалів є важливою інформацією під час планування процесу. Метою даного дослідження є опис методом МКЕ глибини, що порушується, і ширини при вигладжуванні алмазним індентором. Моделювання шляхом кінцевих елементів було виконано за допомогою програмного забезпечення ThirdWave Advantedge 7.601. Вигладжування валу моделювалося на площині. Сила вигладжування регулювалася точним регулюванням параметра глибини різання, при якому видалення стружки не відбувалося, а бажане навантаження могло бути виміряне за силою, що перпендикулярна поверхні заготовки. Як матеріал заготівки була обрана нержавіюча сталь марки X5ХН18-10. У цьому дослідженні проаналізовано три параметри процесу: швидкість (v), подача (f), сила вигладжування (F). Значення цих параметрів було обрано відповідно до методу повного факторного планування експериментів. У цьому дослідженні вимірювали 4 параметри у кожній установці. Перший – це глибина напруження, що є глибиною, на якій виникає напруження по Мізесу не менше 350 МПа, що в 1,5 рази перевищує межу міцності матеріалу. Другий – глибина вигладжування, яка вимірює порушену глибину відповідно до перпендикулярного напруження (напруження Y-Y в позначеннях програми). Третє значення – ширина полірування, яка вимірює задіяну ширину відповідно до напруження зсуву (напруження Y-Z в позначенні програми). Останнім параметром, що вивчався, є максимальне значення тиску, що виникає в поверхневому шарі при вигладжуванні. Автори дійшли висновку, що збільшення перпендикулярної сили дає зростаючу дію на ці параметри, проте можна побачити більше збільшення глибини впливу, ніж глибини напруження. Збільшення поверхневої швидкості призвело до цікавого відкриття. У той час як збільшення швидкості в 1,5 раза призвело до збільшення глибини напружень в середньому в 1,2 раза, глибина впливу залишилася незмінною. Подвоєння подачі призводить до збільшення глибини напружень в середньому в 1,25 рази, у той час як глибина впливу збільшується тільки при більш високих налаштуваннях навантаження і залишається майже незмінною, якщо зусилля вигладжування було відрегульовано до 30 Н. Зміна поверхневої швидкості дуже слабко впливає на ці параметри (зміна 0–16%). Однак збільшення подачі значно впливає на порушену ширину. При збільшенні подачі 1,5 разу спостерігається збільшення ураженої ширини в 1,2–1,8 рази. Ефект зміни сили вигладжування залежить від величини подачі. Як і очікувалося, максимальне значення тиску збільшується зі збільшенням сили вигладжування: збільшення останньої в 1,33 рази призводить до збільшення середнього тиску в 1,2 рази.*

Ключові слова: *вигладжування; план експерименту; МКЕ-моделювання.*