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EXAMINATION OF 3D SURFACE TOPOGRAPHY OF DIAMOND BURNISHED C45 WORKPIECES

Abstract. *Nowadays cold working operations like rolling, burnishing are important finishing methods. In this paper the diamond burnishing of external cylindrical surfaces are studied. The principle of this process is that a pressing tool, which goes along the surface of the workpiece with linear motion having given parameters (e.g. feed) while the workpiece is rotating. Using of diamond burnishing has many preferences: surface roughness of the workpiece is improving, hardness of the surface is increasing while it's micro-structure is also improving. Fatigue strength is increasing significantly due to the compressive residual stress in the subsurface area causing by burnishing. The aim of this study was to examine the influence of different burnishing parameters, such as burnishing speed, feed and force with the using of two different kinematic viscosity oil. For plan and execute the experiments we used the Taguchy type full factorial experimental design method by which empirical formulas can be created easily. The measurement of the surface roughness was executed with Altisurf 520 3D measuring equipment at the Institute of Manufacturing Science. The measured results were evaluated by the comparison of a special correlation formula to determine the optimal combination level of the different parameters in the given interval.*

Keywords: *burnishing; Factorial Experimental Design; 3D surface roughness; experimental investigation; improvement ratio.*

1. INTRODUCTION

While working on machines, most of the stresses are mainly applied to the surface of the different machine parts or to a certain thickness of the surface layer, sothe microgeometry of the machined surface has a great effect on the abrasion resistance of the machine, and its stress-absorbing influence is considerable in the case of fatigue stresses. The surface layer of the machine element is primarily subjected to friction or fatigue [1]. The roughness of the surface of the machine may be reduced more efficiently with life-enhancing mechanical machining than chip removal processes and more and more researches deal with residual stresses [2] and the examination of changing of texture on the surface of the workpiece [3]. The common feature of these material and energy-saving solutions and processes of mechanical surface conditioning is to reduce surface roughness, increase surface hardness by rendering structural defects and dislocations, resulting in significant compressive stress in the surface layer [4-5].Surface-strengthening technologies are differfrom each other in the terms of the relative displacement of the tool and workpiece on the working surfaces. Diamond burnishing which is the subject of the experiment uses sliding relative displacement.

The diamond burnishing process is used for machining external and internal cylindrical surfaces and its main application is automotive crankshafts, inner and outer bearings, etc. form.

The Taguchi type factorial experimental design was used in this research[6], [7] which is valid in between the minimum and maximum values of the input parameters.

In the present experiments input parameters were: burnishing speed (v_b), feed rate (f), burnishing force (F_b) and kinematic viscosity of the used lubricants while the output parameter: arithmetic mean of surface roughness (S_a).

2. APPLICATION OF BURNISHING ON EXTERNAL CYLINDRICAL SURFACE

During burnishing, the roughness of the surface and the solidification of the surface layer are characterized by the interaction between the tool, having a much harder material than the material to be machined, and the surface sliding friction between them. The pressure, required to realize the cold forming, occurs through the overlap between the working tool and the work surface to be formed [8-9].Kinematic relations are demonstrated in Fig. 1 [10].

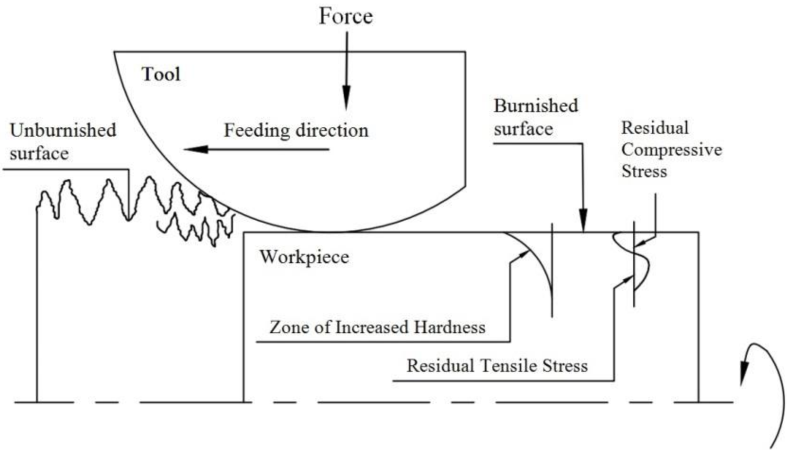


Figure 1 – Kinematics of burnishing [10]

Plastic deformation is caused by this low environment load (does not require huge amount of coolant and lubricant)[10-11]is realized typically in the depth of 0.01÷0.2 mm. According to the purpose of the machining can be distinguished smoothing burnishing (roughness reduction with small overlapping), surface burnishing (forming at a defined depth) and forming burnishing (forming in full cross-section) [1].

Diamond burnishing of outer cylindrical surfaces can be realized on conventional lathes and CNC lathes as well. The applied tool tip can be hardened steel, carbide, ceramics, or natural or artificial diamond.We used polycrystalline diamond which was fixed with a low melting metal in the tool head and sharpened to spherical.When holding the diamond, it must be taken into consideration that its abrasion resistance differs in different directions and the different experiments with artificial diamonds show that the optimum angle between the shafts is 120 ° [1].

3. EXPERIMENTAL CONDITIONS

3.1. Material of the workpiece

The material and the hardness of the workpiece to be burnished can be variousin a very wide range. The object of our study was C45 unworked steel, the chemical composition of which is shown in Table 1.

Table 1 – Chemical composition of workpiece

Elements	C	Si	Mn	Cr	Ni	V	W	Cr	Other
Averaged wt% (weight percent)	0.45	0.3	0.7	-	-	-	-	-	-/S= 0.03

The choice of material for the releaseable structural steel with favorable mechanical properties is justified by the fact that it produces medium wearable parts that are exposed to wear.

3.2. Burnishing parameters

Several researchers have experimentally studied the effect of the technological parameters applied in the burnishing process on surface quality [11], [13], [14]. Based on the results, these are summarized in Fig. 2 [14].

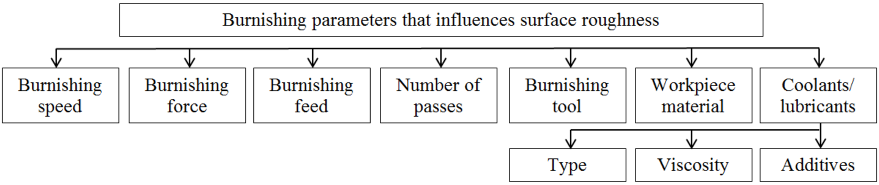


Figure 2 – Kinematics of burnishing [14]

From these parameters the burnishing speed, feed rate and force were choosen, it can be seen in natural dimensions and their transformed values on Table 2 as the matrix of the Taguchi type Full Factorial Experimental Design.

Table 2 – Applied burnishing parameters

Sign of specimen	Parameters of burnishing			Transformed parameters		
	v_b [m/min]	f [mm/rev]	F_b [N]	x_1	x_2	x_3
1	180	0.05	45	-1	-1	-1
2	277	0.05	45	+1	-1	-1
3	180	0.10	45	-1	+1	-1
4	277	0.10	45	+1	+1	-1
5	180	0.05	82	-1	-1	+1
6	277	0.05	82	+1	-1	+1
7	180	0.10	82	-1	+1	+1
8	277	0.10	82	+1	+1	+1

The burnishing operations were carried out on OPTIMUM (OPTIturn L-Series 440) flatbed CNC latheusing PCD (polycrystalline diamond) tool with 3.5 mm radius and the kinematic viscosity of the applied oil was 70 mm^2/s and 220 mm^2/s.

3.3. Measuring of the 3D surface roughness

The measurement of the 3D surface roughness of the specimens before and after burnishing was carried out on AltiSurf 520 type 3D surface roughness tester with optical probe at the Institute of Manufacturing Science. The advantage of using this machine is that the software can not only perform a particular measurement, but can also be done in one setting in succession, so a pre-programmed measurement process can be realized. This means that multiple measurements can be defined one after the other or axis movements can be set [15]. Fig 3 illustrates a state of a measurement, the workpiece was fixed in a prism.

3D surface roughness parameters are classified into five major groups in ISO 25178 standard [16], one of which is the amplitude parameter whose parameters are shown in Fig 4 [17].

The changing of the last surface roughness parameter of Fig. 3, S_a was examined in our investigations which shows the arithmetic mean of the deviation of the surface from the median plane, mathematically expresses the scattering around the median planeη(xi,yj) as it can be seen in Fig 5 [17].

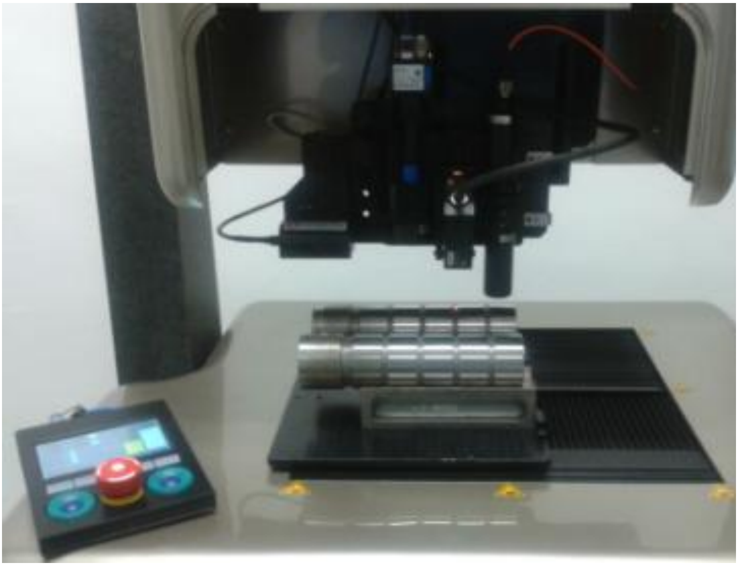


Figure 3 – The measurement process

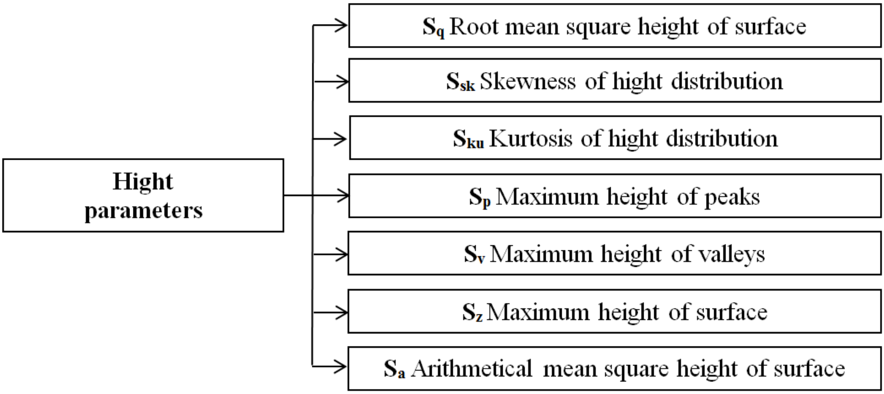


Figure 4 – Classification of height parameters [17]

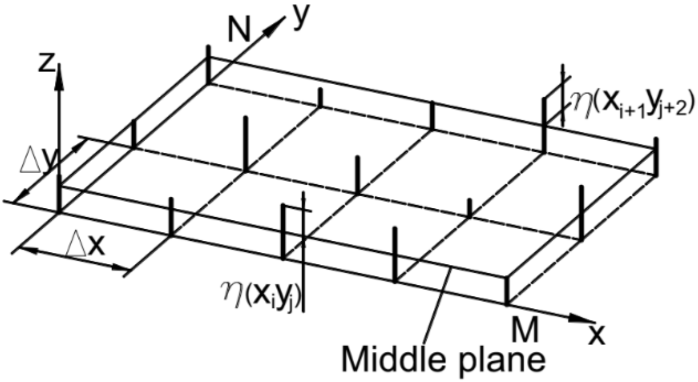
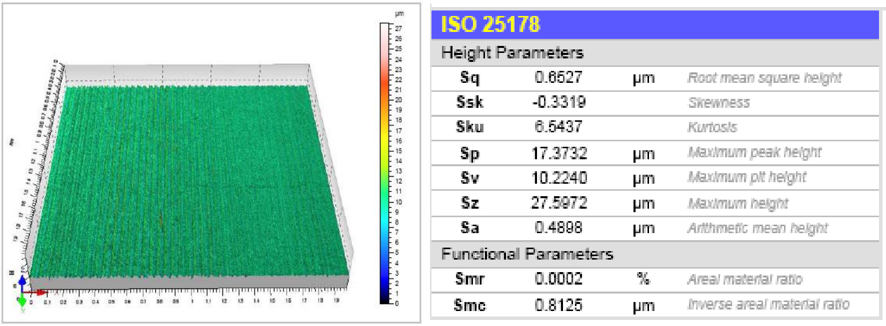


Figure 5 –Basic dimensions for 3D evaluation [17]

For the full characterization of the surface, topographic studies were carried out on certain parts of the specimens. To evaluate the measurement values, we used the software of the roughness measuring instrument (PhoeNix). The topographic recording with the optical sensor shows the characteristic machining traces as well as the surface roughness change of the surface and provides quantifiable characteristics.

Among these recordings, one of the topographic images and the results of the evaluation of the three markedspecimen part is shown in Fig 6.



ISO 25178			
Height Parameters			
Sq	0.6527	µm	*Root mean square height*
Ssk	-0.3319		*Skewness*
Sku	6.5437		*Kurtosis*
Sp	17.3732	µm	*Maximum peak height*
Sv	10.2240	µm	*Maximum pit height*
Sz	27.5972	µm	*Maximum height*
Sa	0.4898	µm	*Arithmetic mean height*
Functional Parameters			
Smr	0.0002	%	*Areal material ratio*
Smc	0.8125	µm	*Inverse areal material ratio*

Figure 6 –Burnished 3D topography

In the case of 16 analyzed topographies, the amplitude parameters that determine the most important functional properties were examined and compared.

4. RESULTS AND EVALUATIONS

As it was mentioned during the experiments, two kinds of kinematic viscosity lubricants were used, a viscosity path of 70 mm^2/s and 220 mm^2/s, hereinafter referred to as Oil 1 and Oil 2.

For evaluation of measured data an improvement ratio was introduced, which is shown in formula (1):

$$\rho_{Sa} = \frac{S_{a_b}}{S_{a_g}} \cdot 100\ \%, \qquad (1)$$

where: ρ_{Sa} Improvement ratio of arithmetical mean square height of surface (Sa). This is a dimensionless ratio, which textures the changing of surface roughness occurring because of manufacturing,

Sa_b Residual stress remains after burnishing,

Sa_g Residual stress remains after grinding.

The smaller the value of ρ_{Sa}, the greater the improvement due to burnishing. Measured data and the improvement ratios of surface roughness parameters, calculated by formula (1), in the case of using Oil 1 and Oil 2, summarized in Table 3.

Table 3 – Measured and calculated datas

Sign of specimen	Sa [μm] with Oil 1		ρ_{Sa}[%]	Sa [μm] with Oil 2		ρ_{Sa}[%]
	after grinding	after burnishing		after grinding	after burnishing	
1	0.3745	0.2373	0.63	0.3603	0.4898	1.36
2		0.2428	0.65		0.3193	0.89
3		0.1917	0.51		0.2085	0.58
4		0.2039	0.54		0.2489	0.69
5	0.3652	0.5148	1.41	0.3733	0.5841	1.56
6		0.6941	1.90		0.5510	1.48
7		0.2235	0.61		0.2393	0.64
8		0.1909	0.52		0.2725	0.73

Application of Factorial Experiment Design method empirical formulas (2) and (3) were created from the calculated values. Calculations and axonometric figures (Fig. 7-8) were prepared using „MathCAD 16.0” software.

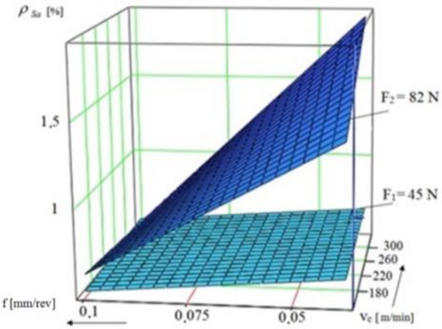


Figure 7 – Changing of improvement ratio of surface roughness using Oil 1

$$\rho_{S_a} = -636.879 + 2.898 \cdot v_b + 1.005 \cdot 10^4 \cdot f + 17.664 \cdot F_b - 40.291 \cdot v_b \cdot f - \\ -0.077 \cdot v_b \cdot F_b - 254.005 \cdot f \cdot F_b + 1.031 \cdot v_b \cdot f \cdot F_b \qquad (2)$$

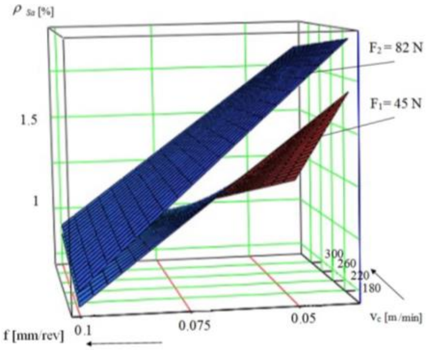


Figure 8 – Changing of improvement ratio of surface roughness using Oil 2

$$\rho_{S_a} = -636.879 + 2.898 \cdot v_b + 1.005 \cdot 10^4 \cdot f + 17.664 \cdot F_b - 40.291 \cdot v_b \cdot f - \\ -0.077 \cdot v_b \cdot F_b - 254.005 \cdot f \cdot F_b + 1.031 \cdot v_b \cdot f \cdot F_b \qquad (3)$$

5. SUMMARY

The paper presents the experiments of diamond burnishing of external cylindrical surface with different types of oil with the settings of different technological parameters. For the improvement of surface roughness, we determined a ratio (ρ_{Sa}) that was formed from the ratio of pre- and post-burnishedresults. Using the

Taguchi typefull factorial experimental design methodology, burnishing experiments were carried out on the surface of a non-heat-treated cylindrical specimen with spherical surface burnishing tool. Our results are illustrated in 3D charts and the following statements are made:

Among the examined parameters, the effect of burnishing force is the most dominant in the improvement characteristic of ρ_{Sa}

In the examined parameter range, the larger ρ_{Sa} surface roughness improvement was observed in the case of the larger feed (f = 0.10 mm / rev)

The setting of larger burnishing force with lower feed rate can lead to the increase of the roughness

Parameters that resulted the lowest and thus the most favorable surface roughness were the following:

- $F = 82$ N; $v_c = 277$ m/min; f = 0.10 mm/rev; $\nu = 70$ mm^2/s

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ЕКСПЕРТИЗА 3D ТОПОГРАФІЇ ПОВЕРХНІ ДЕТАЛІ ОБРОБЛЕНОЇ АЛМАЗНИМИ ВИГЛАДЖУВАЧАМИ С45

Анотація: *В даний час операції холодної обробки, такі як прокатка, полірування, є важливими методами обробки. У даній роботі вивчено алмазне вигладжування зовнішніх циліндричних поверхонь. Принцип цього процесу полягає в тому, що притискний інструмент, який рухається уздовж поверхні заготовки з лінійним рухом, має задані параметри (наприклад, подачу) під час обертання заготовки. Використання алмазного вигладжування має багато переваг: поліпшується шорсткість поверхні заготовки, збільшується твердість поверхні, а також поліпшується її мікроструктура. Втомна міцність значно збільшується через залишкові напруги при стисненні в підповерхневій зоні, які викликані вигладжуванням. Метою даного дослідження було вивчити вплив різних параметрів вигладжування, таких як швидкість, подача і зусилля, з використанням двох масел з різною кінематичною в'язкістю. Для планування і проведення експериментів ми використовували метод повного факторного планування експериментів типу Тагучі, за допомогою якого можна легко створювати емпіричні формули. Вимірювання шорсткості поверхні було виконано за допомогою вимірювального обладнання Altisurf 520 3D в Інституті виробничих наук. Виміряні результати оцінювалися за допомогою спеціальної формули кореляції для визначення оптимального рівня комбінації різних параметрів в даному інтервалі. Для поліпшення шорсткості поверхні ми визначили співвідношення, яке було сформовано зі співвідношення результатів до і після обробки. Використовуючи методологію повних факторних експериментів типу Тагучі, експерименти по зміцненню проводилися на поверхні необробленого циліндричного зразка за допомогою вигладжувача сферичної форми. Результати проілюстровані на тримірних графіках і зроблені наступні висновки: серед досліджених параметрів вплив сили тертя є найбільш домінуючими в характеристиці поліпшення співвідношення. У досліджуваному діапазоні параметрів збільшення шорсткості поверхні спостерігалося в разі більшої подачі (0,10 мм/об). Налаштування більшої сили притиску при більш низькій швидкості подачі може призвести до збільшення шорсткості. Параметри, які привели до найнижчої і, отже, найбільш сприятливої шорсткості поверхні, були наступними: сила притиску 82Н, швидкість 277 м/хв, глибина 0,10 мм/об.*

Ключові слова: *вигладжування; проектування факторних експериментів; 3D шорсткість поверхні; експериментальне дослідження; коефіцієнт поліпшення.*