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EXPERIMENTAL EXAMINATION OF SURFACE MICRO-HARDNESS IMPROVEMENT RATIO IN BURNISHING OF EXTERNAL CYLINDRICAL WORKPIECES

Abstract. *This paper deals with the experimental examination of surface micro-hardness improvement ratio in burnishing of external cylindrical workpieces. The material of the examined workpiece was AISI 304 austenitic stainless steel. In our experiments, we investigated the sliding frictional burnishing of an outer cylindrical surface when the burnishing tool had a diamond material-grade spherical tip. Using the full factorial experimental design technique, we aimed to determine how the changes in burnishing parameters, i.e., burnishing speed, burnishing feed, and burnishing force effect on the changes of surface micro-hardness and surface micro-hardness improvement ratio. Based on examinations, the best burnishing parameter combination could be selected.*

Keywords: *AISI 316Ti austenitic stainless steel; slide diamond burnishing; micro hardness; improvement ratio of micro hardness.*

1. INTRODUCTION

Due to their increased corrosion resistance, stainless steels are widely used in various fields of engineering practice, such as food industry, chemical industry, and automotive industry. The most common requirements for the surfaces of parts made of such steels are low roughness, high micro-hardness and wear resistance. These requirements can largely be satisfied by the use of cold-plastic burnishing technologies.

Sliding friction burnishing is kinematically similar to turning, but instead of the insert of the cutting tool, the deforming element is a large radius sphere tip that is moved by applying a certain amount of pressure to the surface to be machined. This creates a plastic deformation on the surface of the workpiece and in the layers close to the surface (Fig. 1) [1].

Burnishing improves the surface roughness, creates compressive residual stress and increases the hardness. The implementation possibilities of surface plastic deformation based on the work of Maximov et al. [2] are illustrated in Fig. 2.

Dynamic methods can almost always be used indefinitely to treat complex surfaces. Static methods are more suitable for improving the surface integrity of rotationally symmetric parts. Sliding friction burnishing was classified in detail by Maximov et al. [3] and analysed from different perspectives. Examples of classification criteria were: a) the object studied (surface integrity, functional characteristics of burnished surfaces, physical nature of the process), b) the material and shape of the deforming element, c) the method of testing, d) the machined material qualities (steel, non-ferrous metal alloys), e) type of machined surface (outer cylindrical surfaces, inner cylindrical surfaces, flat surfaces, complex surfaces, discontinuous cylindrical surface), f) examination of process parameters (ironing force, ironing depth, feed, ironing speed, the number of passes, the lubricant, the radius of the spherical tool, the diameter of the cylindrical tool).

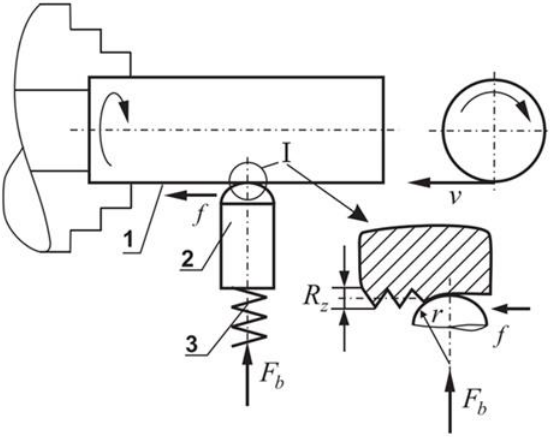

Figure 1 – Schematic of sliding friction burnishing [1]
1 - workpiece, 2 - forming element, 3 - spring

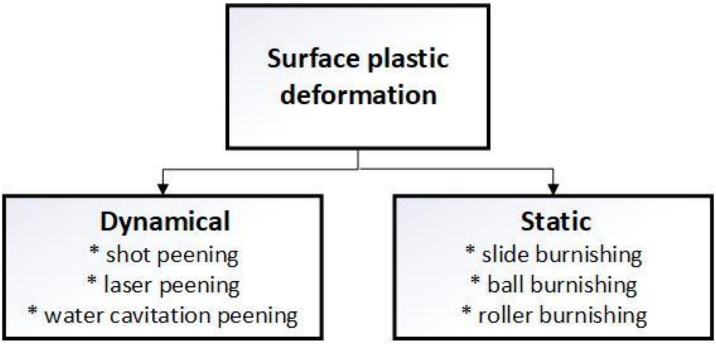

Figure 2 – Implementation possibilities of surface plastic deformation [2]

In the analysis of surface integrity, it was found that 33% of the more than 100 dissertations examined dealt with roughness while 21% dealt with micro-hardness. 79% of the studies implemented sliding friction ironing with a diamond deforming part. Another interesting fact is that three-quarters of the studies used an experimental test method. 75% of the studies analysed focused on the examination of the external cylindrical surface. The three most commonly studied parameters were ironing force, feed, and ironing speed. 65% of the reinforced workpieces were made of steel, of which 28% dealt with the cold-plastic burnishing of stainless steels. In the following, we deal with the research of the burnishing of stainless steels.

2. COLD FORMING MACHINING OF STAINLESS STEELS

The research by Shiou et al. [4] aims to develop a new burnishing tool embedded in a measuring cell integrated with a CNC lathe that improves the hardness of smoothly turned AISI420 stainless steel. Based on the experimental results, the appropriate combination of process parameters is as follows: sphere material WC, burnishing force 650 N, feed rate 0.05 mm/rev, speed 25 m/min, coolant-lubricant (oil/water concentration 1/20) and the number of passes is 3. The surface hardness of the smoothly turned specimen could be increased from HRc 51 to HRc 52.5 on average by using the appropriate process parameters. Sachin et al [5] performed diamond burnishing in a minimal quantity lubrication (MQL) environment on 17-4PH stainless steel. Their aim was to investigate the effect of process parameters on surface integrity characteristics, including surface hardness, when using a new, modified tool. With their burnishing, they achieved that the improved maximum surface hardness of 405HV using diamond spheres with radii of 3 mm and 4 mm. The paper of Varga and Ferencsik [6-7] deals with the analysis of hardness of diamond burnished workpiece surfaces of low alloyed aluminium. Within the studied parameter range, the rate of improvement in terms of surface micro-hardness was maximized at 13.67%, which could be increased by increasing the force and by decreasing the feed rate.

3. EXPERIMENTAL CONDITIONS

3.1. Material, specimen

Austenitic chromium-nickel stainless steel 1.4301/AISI 304, often used for equipment in the chemical, oil and food industries, was the subject of the experiment. It is characterized by high corrosion resistance and easy formability. Its chemical composition is given in [7], its mechanical properties in Table 1.

Table 1 – Chemical composition of AISI 304 stainless steel (wt. %) [8]

C %	Si %	Mn %	P %	S %	Cr %	Ni %	N %
≤ 0.07	≤ 1.00	≤ 2.00	≤ 0.045	≤ 0.015	17.5 -19.5	8.0 - 10.5	≤ 0.11

Table 2 – Mechanical properties of AISI 304 stainless steel at 20°C [8]

Hardness HB 30	0.2% Yield strength, Rp	Tensile strength, Rm	Elongation A5	Modulus of elasticity
≤ HB	≥ N/mm²	N/mm²	≥ %	kN/mm²
215	190	500-700	45/35	200

The physical properties of AISI 304 stainless steel at 20°C were [8]: Density 7.9 g/cm³, Specific heat capacity 500 J/kg K, Thermal conductivity 15 W/m K, and Electrical resistivity 0.73 Ω mm²/m.

Geometrical dimensions of the specimens used for the reinforcement experiments: 5 adjacent cylindrical surfaces with a diameter of Φ49.48 mm and a length of 26 mm. The machining parameters for the fine turning of the test piece before ironing were: cutting speed v_c = 90 m/min, feed f = 0.05 mm/rev and the depth of cut a_c = 0.05 mm. Micro-hardness data can be found in Table 4.

Figure 3 – The technological realization of sliding burnishing process

Burnishing of outer cylindrical surfaces can be executed on conventional universal lathe or up-to-date CNC lath. The previous one was applied because of it rigidity as can be seen in Fig. 3.

3.2. Research methodology, measuring techniques

For the present series of experiments, we examined the effect of three factors, each at 2–2 levels according to the method of factorial experiment design [9-10].

The advantage of this method is that an empirical function relations can be written between the input (independent) parameters and the output (dependent) variable. Independent variables are called factors. The different set values of the factors are called levels.

The burnishing experiments were performed on a renovated, sufficiently rigid EU-400/01 type SZIM lathe at the Institute of Manufacturing Sciences of the University of Miskolc. The material of the burnishing tool was PCD and its radius was R = 3.5mm. Manual application of lubricant, type SAE 15W-40, was small.

The experimental design matrix of the reinforcement parameter variants is shown in Table 3.

Table 3 – Burnishing parameter variants

No.	Adjusted parameters			Transformed parameters		
	v [m/min]	f [mm/rev]	F [N]	X_1	X_2	X_3
1	41.17	0.0125	30	-1	-1	-1
2	58.26	0.0125	30	+1	-1	-1
3	41.17	0.0500	30	-1	+1	-1
4	58.26	0.0500	30	+1	+1	-1
5	41.17	0.0125	40	-1	-1	+1
6	58.26	0.0125	40	+1	-1	+1
7	41.17	0.0500	40	-1	+1	+1
8	58.26	0.0500	40	+1	+1	+1

The following burnishing parameters were examined: burnishing speed, feed rate and burnishing force, as it can be seen on Table 3. Table 3 contains the burnishing parameters in natural dimensions and in transformed (dimensionless) way.

3.3. Measuring of micro-hardness of the surface

The surface hardness of the test pieces was measured (before and after ironing) on an (Wilson Instruments Tukon 2100B) hardness tester at the Institute of Metallurgy, Plastic Formation and Nanotechnology of the Faculty of Metallurgical Engineering. The device measures Vickers hardness too. The principle of it, as is usually the case with all hardness measurements, is to examine how the test material withstands plastic deformation using a standard resource. During the measurement, a 136 ° diamond pyramid was pressed with 1 N force for 10 seconds on the surface to be measured at 3 points along a generatrix.

Figure 4 illustrates a state of the measurement process. In our investigation we have created a dimensionless ratio (1) to make the changing of surface micro-hardness more visible.

$$IRHV = \frac{HVa - HVb}{HVa} \cdot 100, \% \qquad (1)$$

where

IRHv is the ratio of surface micro-hardness improvement (%).
HVb is the surface micro-hardness before burnishing process.
HVa is the surface micro-hardness after burnishing process.

The highest the value of IRHV, the greater is the improvement. The measured data and the calculated improvement ratios are summarized in Table 4.

Table 4 – Measured values and calculated improvement ratios

No.	$HV\,1$		IRHV, %
	After Turning	After Burnishing	
1	316,00	370,33	17,19
2	341,00	360,00	5,57
3	324,00	379,67	17,18
4	319,33	381,67	19,52
5	310,67	383,67	23,50
6	308,67	365,00	18,25
7	318,67	381,67	19,77
8	313,67	384,33	22,53

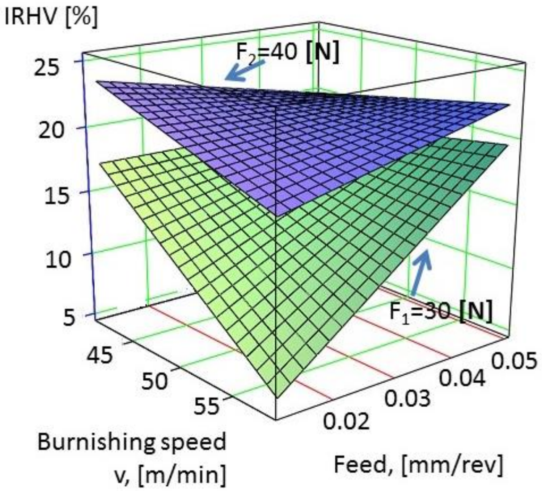

Figure 4 – Changing of surface micro-hardness improvement ratios

Application of Full Factorial Experiment Design method empirical formula (2) could be created from the calculated values. Calculations and axonometric figure (Fig. 4) was prepared using „MathCAD 15.0" software.

$$IRHV = 94.119 - 2.419 \cdot v - 1.746 \cdot 10^3 \cdot f - 1.257 \cdot F + 49.634 \cdot v \cdot f + 0.049 \cdot v \cdot F + 28.304 \cdot f \cdot F - 0.928 \cdot v \cdot f \cdot F \qquad (2)$$

4. SUMMARY AND DISCUSSIONS

The paper deals with the experimental analysis of sliding burnishing when the material of the workpiece is austenitic chromium-nickel stainless steel. Experimental parameters were the burnishing speed, feed rate and burnishing force. The aim of the experiments was to determine the effect of the change of these parameters to the surface micro-hardness.

On the base of the present research work it can be stated:

- Among the examined parameters the effect of burnishing force is the most dominant and it is followed by the feed, and the less dominant parameter is the burnishing speed.
- The best improvement ratio of surface micro-hardness resulted when the burnishing parameters were as follows: F=40 N, f=0.0125 mm/rev and v=41.17 m/min.

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ЕКСПЕРИМЕНТАЛЬНЕ ДОСЛІДЖЕННЯ СТУПЕНЯ ПІДВИЩЕННЯ МІКРОТВЕРДОСТІ ПОВЕРХНІ ПРИ ВИГЛАДЖУВАННІ ЗОВНІШНІХ ПОВЕРХНОСТЕЙ ЦИЛІНДРИЧНИХ ДЕТАЛЕЙ

Анотація. *Робота присвячена експериментальному дослідженню ступеня підвищення мікротвердості поверхні при вигладжуванні зовнішніх поверхонь циліндричних деталей. Вигладжування тертям ковзання по кінематиці аналогічно токарній обробці, але замість вставки різального інструменту, деформуючий елемент являє собою сферичний наконечник з великим радіусом, який переміщається шляхом застосування притиску з певною силою до оброблюваної поверхні. Це створює пластичну деформацію на поверхні заготовки і в шарах, близьких до поверхні. Такий процес обробки покращує шорсткість поверхні, створює залишкову напругу стиснення і збільшує твердість. Матеріалом досліджуваної заготовки була аустенитна нержавіюча сталь AISI 304. У даних експериментах було досліджено фрикційне вигладжування ковзання зовнішньої циліндричної поверхні, коли вигладжувальний інструмент мав сферичний наконечник зі штучного алмазу. Використовуючи методику повного факторного експерименту, переслідувалася мета визначити, як зміни параметрів вигладжування, такі як: швидкість вигладжування, подача і сила притиску вигладжувача впливають на зміни мікротвердості поверхні і коефіцієнту поліпшення мікротвердості поверхні. На підставі досліджень можна вибрати кращу комбінацію параметрів цього процесу. Для даної серії експериментів було досліджено вплив трьох чинників, кожен на 2-2 рівнях відповідно до методу факторного планування експериментів. Перевага цього методу полягає в тому, що між вхідними (незалежними) параметрами і вихідною (залежною) змінною може бути записана емпірична функція. На підставі проведеного дослідження можна констатувати, що серед розглянутих параметрів вплив сили притиску вигладжувача є найбільш домінуючим, за ним слідує подача, а менш домінуючим параметром є швидкість вигладжування. Найкращий коефіцієнт поліпшення мікротвердості поверхні був досягнутий, коли параметри процесу вигладжування були наступними: F = 40 Н, f = 0,0125 мм / об і v = 41,17 м / хв.*

Ключові слова: *аустенітна нержавіюча сталь AISI 316Ti; алмазне вигладжування; мікротвердість; коефіцієнт поліпшення мікротвердості.*