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IMPROVEMENT OF SURFACE MICRO-HARDNESS OF 41CR4 STEEL BY MEANS OF SURFACE PLASTIC DEFORMING

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ABSTRACT

Slide burnishing (SB) and roller burnishing (RB) are static mechanical surface treatment methods, based on surface plastic deforming of the metal components and intended to improve the surface integrity (SI) of these components. This article presents the outcomes of comparison between slide diamond burnishing and RB under "micro-hardness" criterion. Due to the sliding friction contact, SB achieves significantly bigger micro-hardness compared to RB. The significant increase of burnishing force leads to slightly increase of the micro-hardness.

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1. INTRODUCTION

The complex set of surface layer qualities of structural and machine metal components is known as the surface integrity (SI). Improvement of SI of these components requires a relevant approach for treating the surface layers, whereby the required set of properties for these layers is achieved: grain refinement microstructure, residual compressive stress, maximum depth of the compressive zone, increased microhardness and minimum roughness. Such approach is the mechanical surface treatment (MST) process (no alteration in the chemical composition). The essence of MST is the plastic deforming of the surface peaks created by sliding friction or rolling contact between a deforming element and the surface being treated. The peaks of the relief are plastically deformed, as the metal flows to the free valleys. As a result, the surface layer undergoes strain hardening. Thus, the surface layers are characterized by low roughness, increased micro-hardness and useful residual compressive stresses. Such SI ensures increased fatigue strength and wear resistance of the corresponding component.

The methods used to implement MST are of two types: dynamic (such as shot peening, laser peening, water cavitation peening) and static (roller/ball burnishing, slide burnishing). The static methods are suitable for treating rotational surfaces. They have a wider application in comparison with the dynamic methods since their parameters can be controlled more easily in order to obtain the desired SI. These static methods are known under the common name burnishing methods and are the object of the present study.

The resulting SI depends on the ratio between the burnishing force and the temperature factor characterizing the corresponding burnishing process. The amount of the heat generated is primarily a result from the friction forces between the deforming element and the surface being treated. The increased temperature causes a softening effect of the surface layers, which changes the SI in qualitative and quantitative aspect. On the other hand, the tangential sliding friction contact favors fracturing and deforming of the grains in tangential direction, parallel to the burnishing velocity. As a result, a modified microstructure is obtained, which is a physical basis for increasing the material fatigue strength. That is why the fundamental difference between the different burnishing methods is due to the contact type (sliding or rolling) between the deforming element and the surface being treated. According to this feature, the main burnishing methods are roller/ball burnishing (RB/BB) (Fig. 1) and slide burnishing (SB) (Fig. 2). The hybrid static burnishing methods exist, where the deforming element is: a) a ball whose contact with the surface being treated can be rolling contact at some moments in time and sliding friction in others [1-6]; b) a roller whose contact with the surface being treated is both rolling and sliding friction contact [7,8]. These hybrid methods are not a subject of the present study.

It is obvious that BB with hydrostatic sphere (Fig.1b) and SB with a spherical-ended tool (Fig. 2) can be realized with one and the same geometric parameters (diameter of the deforming sphere and diameter of the surface being treated), burnishing force and manufacturing parameters (feed rate and burnishing velocity). The difference in SI obtained under these conditions will only be due to the type of the tangential contact, respectively rolling and sliding friction. Therefore, a thorough study of SI depending on the tangential contact is of major interest for engineering practice.

SB is implemented with simple devices and tools, which is its main advantage. SB is the common name for burnishing, which is implemented via sliding friction

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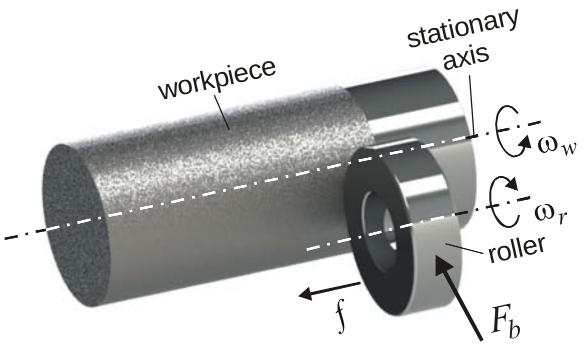
contact. When the deforming element is made of diamond (artificial or natural), the method is referred to as diamond burnishing (DB) or slide diamond burnishing (SDB). General Electric first introduced DB in 1961 in order to improve the SI of the treated components [9].

The nature of SB differs from that of burnishing with a rolling contact (R/BB). In SB, the tangential contact between the deforming element and the surface being treated is one of sliding friction. Regardless of the low friction coefficient obtained in the case of using a synthetic diamond as a deforming element, the friction forces work is significant and dissipates into heat. Therefore, the deforming process in SB has a thermo-mechanical nature and the heat generated is the reason thermoplastic deformations emerge. Thus, all of the major effects of SB (smoothing, cold work, introducing residual compressive stresses) depend on the heat generated, as the latter is the cause of so-called softening effect of the surface layer.

Counterpoint of SB are BB and RB methods, in which the tangential contact between the deforming element and the surface being burnished is rolling friction. As a result from this contact the heat generated due to the friction forces is incomparably smaller.

The purpose of this article is to conduct a comparative analysis of the micro-hardness obtained after SB and BB/RB.



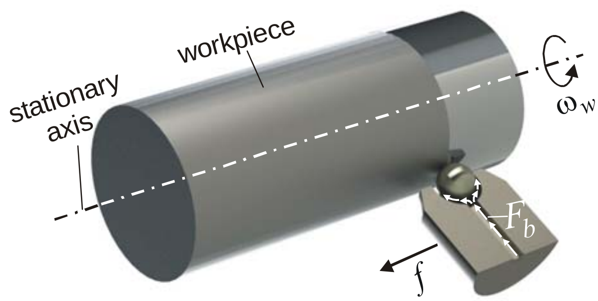


Fig. 1. Scheme of: a) single roller burnishing; b) ball burnishing with a hydrostatic sphere

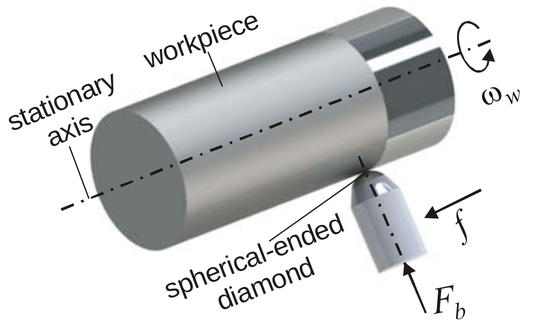


Fig. 2. Scheme of slide burnishing with spherical-ended tool

2. EXPERIMENT

2.1. Conditions of the experiment

2.1.1. Material

The used material in the experiment was 41Cr4 medium-carbon low-alloy steel with chemical composition similar (with the exception of the carbon content) to that of 37Cr4. The average mechanical characteristics of this batch of 41Cr4 steel was established in our "Testing of Metals" laboratory: Young's modulus $E = 2\times 10^5\ MPa$; yield limit $\sigma|_0 = 789\ MPa$; ultimate stress $\sigma_u = 986\ MPa$; elongation $A_5 = 10{,}3\%$; transverse contraction $z = 26\ \%$.

2.1.2. Specimens preparation

The specimen preparation was conducted on CNC T200 lathe. In order to determine the microhardness a specimen with a length of $100\ mm$ and diameter of $20\ mm$ was used. The specimen was produced through a technology which removes (at least partially) all residual stresses except those introduced by precision turning. The following processes were administered: turning, heat treatment – annealing $550°C$ for $2.5h$, precision turning, burnishing – the first specimen was slide burnished and the other two specimens were roller burnished using one and the same process parameters with the exception of burnishing force. Each specimen was clamped to one side with the chuck and supported on the other side. Precision turning and burnishing were carried out in one clamping process to minimize the concentric run-out in burnishing. A DNMG 50608 RF carbide cutting insert was used for precision turning and an average roughness of $R_a = 1.25\mu m$ (before burnishing) was achieved. Special burnishing devices (Fig. 3) were designed and manufactured in order to conduct SB and single-roller burnishing (RB). A policristalline diamond tool with spherical tip was used for SB. The SB parameters were: diamond radius $r = 4mm$, burnishing force $F_b = 300N$, feed rate $f = 0.05mm/rev$, burnishing velocity $v \approx 100m/min$. The RB was conducted using a toroidal roller with outer diameter $d = 26mm$ and radius of the toroid surface $r = 4mm$. The feed rate and the burnishing velocity were respectively $f = 0.05mm/rev$ and $v \approx 100m/min$. Two burnishing forces were used for RB: $F_b = 300N$ and $F_b = 1300N$. The burnishing processes were fulfilled in the presence of Hacut 795-H lubricant-cooler. The turning and burnishing were conducted from end to end of each specimen.

2.1.3. Micro-hardness

After burnishing micro-hardness – depth profiles were measured on cross-section specimens, applying HV 0.05 hardness testing. RMT-3 micro-hardness tester was used.

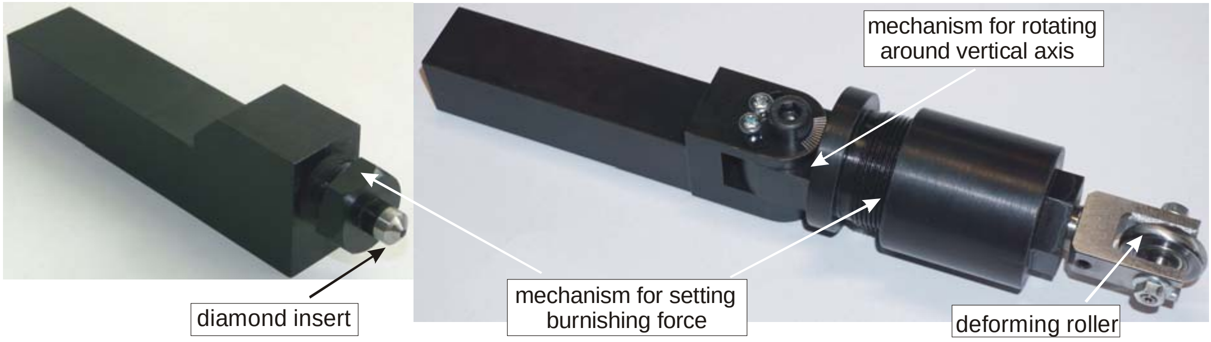


Fig. 3. Burnishing devices: a. diamond burnishing; б. single-roller burnishing

2.2. Experimental results

Fig. 4 shows the measured micro-hardness. Obviously, SB provides a significantly larger microhardness than RB. The additional measurements on the cylindrical surface of the sample subjected to SB showed even higher micro-hardness: $HV0.05 = 412$ and $HV0.025 = 446$. This result can be explained by microstructure obtained (Fig. 5). After SB, the modification of the microstructure is observed in direction of grain refinement and creation of texture (Fig. 5a) due to the tangential friction contact. Regardless of the burnishing force, RB can not achieve such microstructure modification (Fig. 5b,c).

3. CONCLUSION

- Due to the sliding friction contact, SB achieves significantly bigger micro-hardness compared to RB.
- The significant increase of burnishing force leads to slightly increase of the micro-hardness.

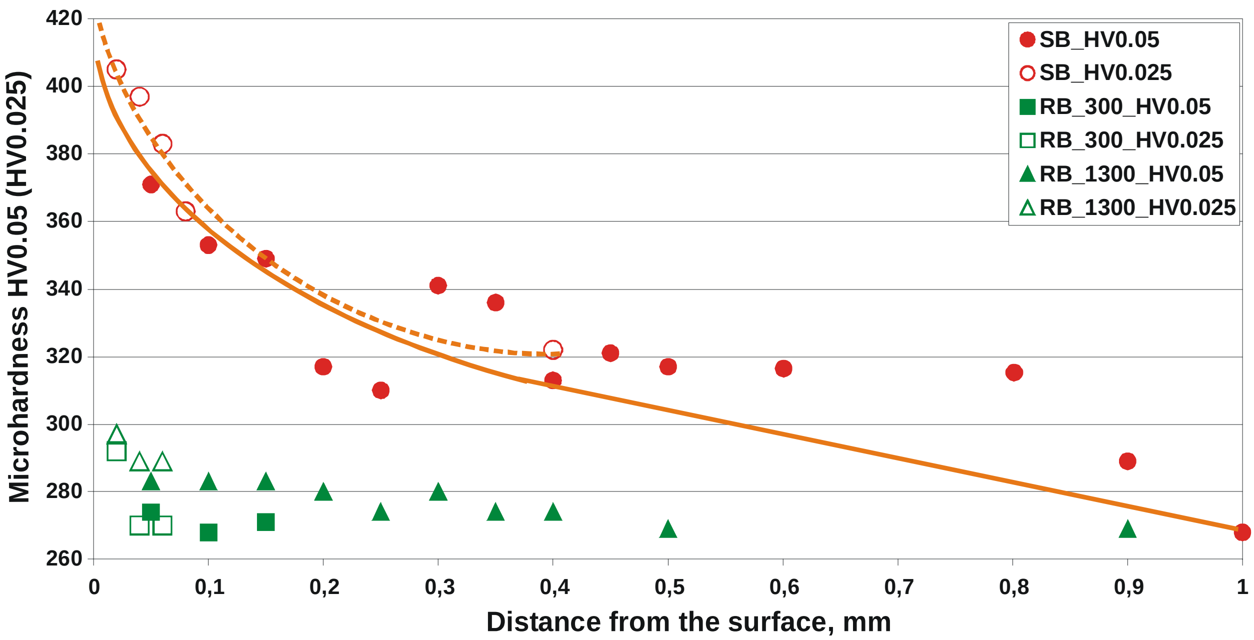
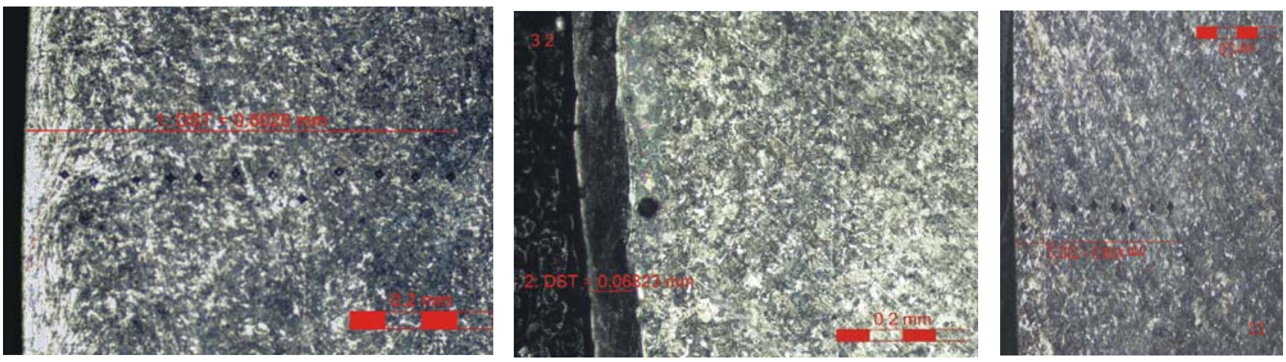


Fig. 4. Microhardness obtained



a. b. c.

Fig. 5. Microstructure: a. after SB; b. after RB with $F_b = 300N$; c. after RB with $F_b = 1300N$

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