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CONTRIBUTION OF BURNISHING TO THE MICROSTRUCTURE AND TEXTURE IN SURFACE LAYERS OF CARBON STEEL

WPŁYW NAGNIATANIA NA MIKROSTRUKTURĘ I TEKSTURĘ W POWIERZCHNIOWYCH WARSTWACH STALI WĘGLOWEJ

Ring samples of Ck45 steel have been subjected to burnishing with use of three variants; rolling ball, rolling mill and sliding ball. Texture and microstructure were examined on the surface and in the longitudinal cross-section of the samples cut out from the outer part of the samples after burnishing as well as after subsequent frictional wearing. The texture of the surface layer was characterised by the main orientation $\{110\}<112>$ for the rolling ball, while for the rolling mill, except the $\{110\}<112>$, the $\{221\}<114>+\{112\}<110>$ orientations were additionally stated. The surface texture of the sample deformed by sliding ball was described as the $\{221\}<114>+\{001\}<110>$. All the samples hardened by burnishing were subjected to the subsequent wear at dry friction conditions and revealed the $\{221\}<114>$ type of the texture, independently of the former state. Similarity between the shear texture of the bcc materials and the texture after burnishing was stated.

Pierścieniowe próbki ze stali 55 poddane zostały nagniataniu w trzech wariantach: tocznie kulką, tocznie krążkiem i ślizgowo kulką. Analizowano teksturę i mikrostrukturę na powierzchni i na przekroju poprzecznym próbek wyciętych z zewnętrznego zdeformowanego obszaru materiału. Tekstura warstw wierzchnich w przypadku nagniatania tocznie kulką charakteryzowała się główną orientacją typu $\{110\}<112>$, zaś dla nagniatania tocznie krążkiem, obok orientacji $\{110\}<112>$ występowały $\{221\}<114>+\{112\}<110>$. Teksturę po nagniataniu ślizgowo kulką opisano jako $\{221\}<114>+\{001\}<110>$. Wszystkie utwardzone poprzez nagniatanie próbki poddane zostały procesowi zużycia w warunkach tarcia suchego. Po procesie zużycia stwierdzono teksturę typu $\{221\}<114>$ niezależnie od wyjściowego stanu materiału. Zaobserwowano podobieństwo pomiędzy teksturą ścinania tworzącą się w metalach o sieci A2, a powstającą w procesie nagniatania.

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1. Introduction

Surface treatment by burnishing leads usually to evidence enhancement of the total life and fatigue strength of materials. An increase of hardening and smoothness of the surface region of material connects with a compressive stress state obtained by optimisation of the parameter of plastic deformation. This process minimises the crack growth and retards failures of machine parts [1 – 4]. The plastic deformation is usually localised in the layers situated just beneath the surface [4, 6, 7]. The tools used in burnishing are mostly in a form of roll or mill producing a local deformation of elastic, elastoplastic or plastic type. Because of a respectively high hardness of the burnishing tool, the main deformation is localised in the surface layer of hardened material. This leads to a change in the macroscopic shape of grains as well as in the preferred crystallographic orientation. The grains are usually refined and elongated in the direction of the highest strain. Moreover, the burnishing increases the mechanical-, thermal-, and chemical- resistance of the material surface layer. This increase is due to the formation of the new convenient microstructure and a rise of hardness caused by the favourable residual stress distribution of a compressive type. The burnishing also improves the smoothness of the surface of the material leading to prosperous exploitation properties.

Deformation process by burnishing can be divided into two phases; the first is elastic strain which transforms later into plastic deformation [4 – 6]. Experimental results proved that in the case of the activity of the normal forces, the initial plastic deformation occurs in a given depth of the area around the B i e l a j e v point [3, 5, 6]. The maximum of the contact stress is observed in a dept beneath the surface while the stresses just close to the surface are about zero or even zero, which was proved in the previous author examinations (Fig. 1) [5, 6]. It can be assumed that when the contact forces appear, their raise cause an increase of the deformed regions [3, 4]. The transformation is observed from the contact to the contact-movement scheme of deformation. The shifting of the area of the maximal shear stress into the surface is observed. An analyse of different types of burnishing shows that two basic movements appear in each case i.e. causing deformation and shifting [7]. The deformation movement is usually perpendicular to the surface while the shifting movement is parallel to the surface and can be initiated by the tool or machining object. Thus, the convenient scheme of the deformation is to make the shifting movement during the deformation process [7]. On the other hand, properties of surface layer are mostly related to the variants of burnishing. Experimental results as well as the process modelling confirmed such a relationship [8, 9]. It is obvious that burnishing leads to a unique fibre morphology in the surface layers and such a morphology with refined and elongated grains in the direction of the maximum strength is usually characterised with a crystallographic texture as well [10]. Moreover, the type of the texture could determine the strain state during deformation i.e. the contribution of the normal or shear stresses to the plastic deformation which was stated experimentally for the f.c.c. metals and alloys [11].

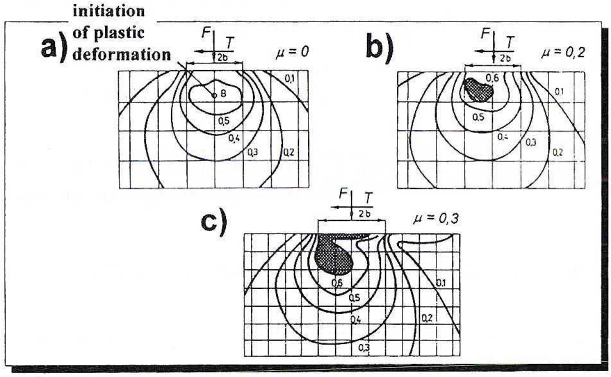

Fig. 1. Isochrom pattern in the contact zone [7]; loading with normal force $T/F = \mu = 0$ (a); loading with normal and contact forces $T/F = \mu = 0.2$, formation of plastic deformation zone (b); loading with normal and contact forces $T/F = \mu = 0.3$, growth and movement of plastic deformation zone (c)

The aim of this work was to study the relationship between the applied variant of burnishing using the different shape of tool and the revealed microstructure and type of the texture in the surface layers of machined material.

2. Materials and method of examination

Examinations were carried out on ring-shape samples of Ck55 steel of the following sizes: internal diam. 40 mm; external diam. 20 mm; length 25 mm. Samples were water quenched from 840°C and subsequently tempered at 500°C for 2.5 h.

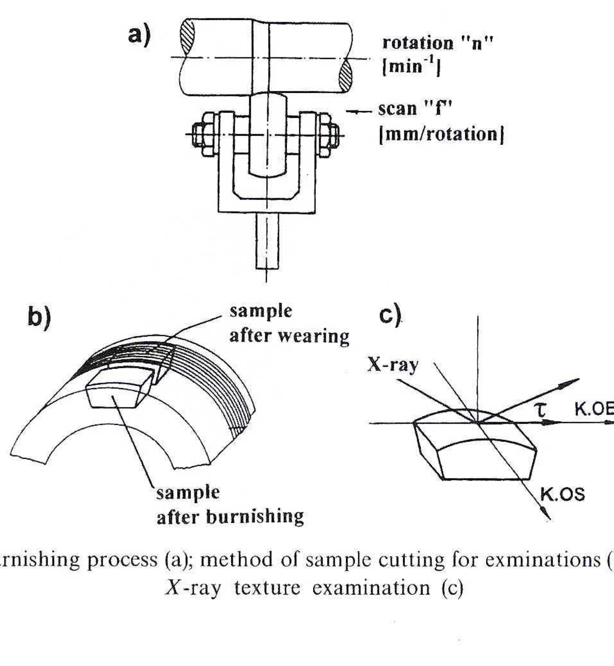

Fig. 2. Scheme of burnishing process (a); method of sample cutting for exminations (b); sample position in X-ray texture examination (c)

Three methods of burnishing were applied:

1. by rolling ball with $R_k = 9.25$ mm; $F = 5$ kP,
2. by rolling mill with $R_k = 15$ mm; $F = 5$ kP; scan $f = 0.45$ mm/rotation,
3. by sliding ball with $R_k = 9.25$ mm; $F = 1.2$ kP.

The scheme of burnishing, the method of sample cutting for the structure and texture examinations and the sample position in X-ray diffraction study of texture (XRD) are explained in Fig. 2a, b, c, respectively.
Microstructure of the surface and in the perpendicular cross-section after burnishing and wear test at dry condition was examined with SEM. Texture of the surface was measured for the samples after burnishing as well as after wear test. The results were presented in the form of the $\{110\}$ pole figures and the diagram of reflection intensity for the chosen diffraction lines i.e. 110, 200, 211. Microstructure was examined with use of a Philips XL30 SEM while the XRD was performed with use of a Philips X-ray diffractometer PW1710 under the control of APD program.

3. Results and discussion

The microstructure of the material surface and in the cross-section after the applied type of burnishing is presented in Figs. 3 – 5, respectively. The left pictures show the microstructure after burnishing and the right ones after the wear test of the

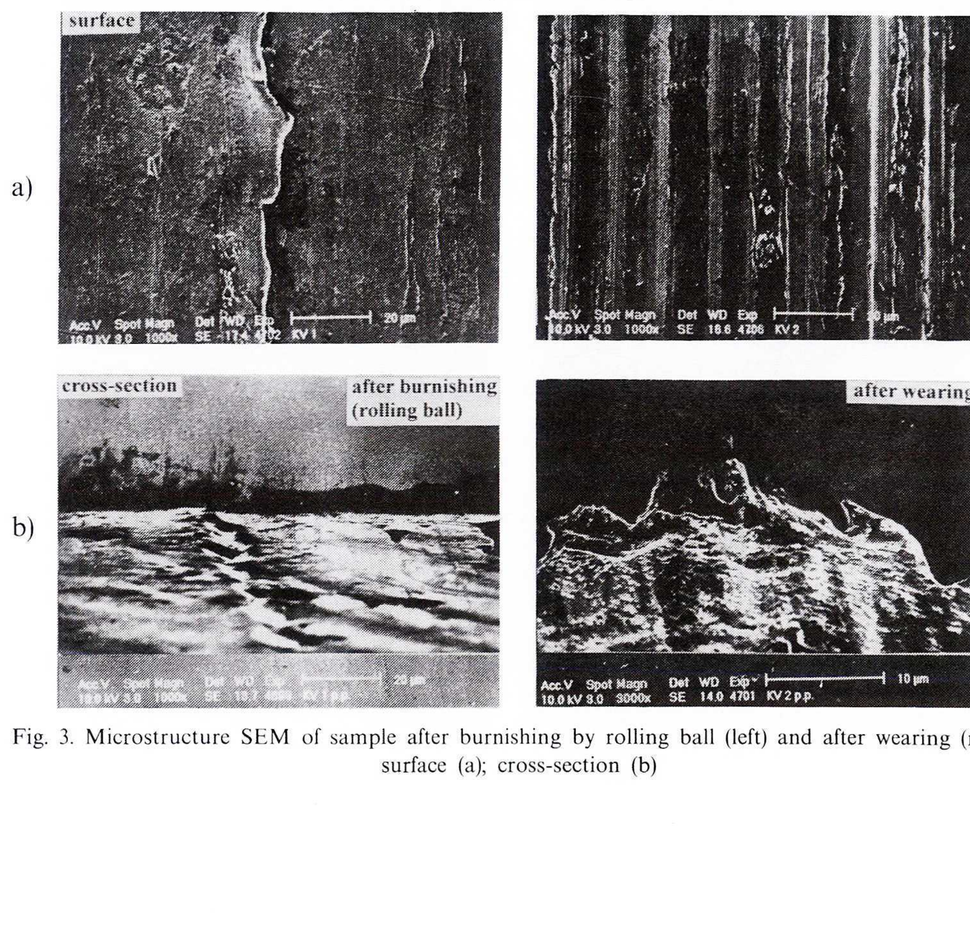

Fig. 3. Microstructure SEM of sample after burnishing by rolling ball (left) and after wearing (right); surface (a); cross-section (b)

a)

b)

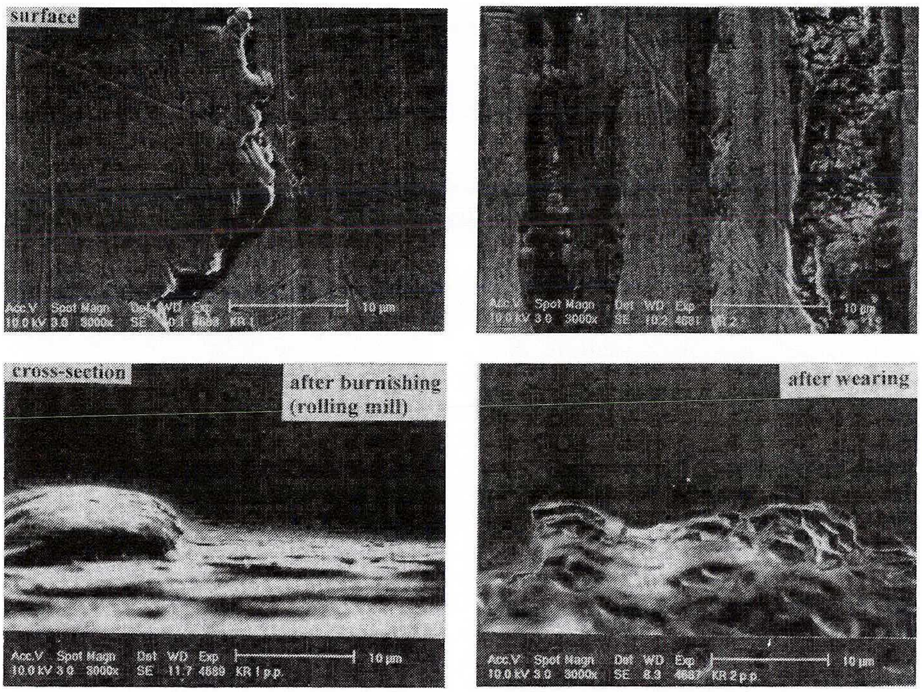

Fig. 4. Microstructure SEM of sample after burnishing by rolling mill (left) and after wearing (right); surface (a); cross-section (b)

a)

b)

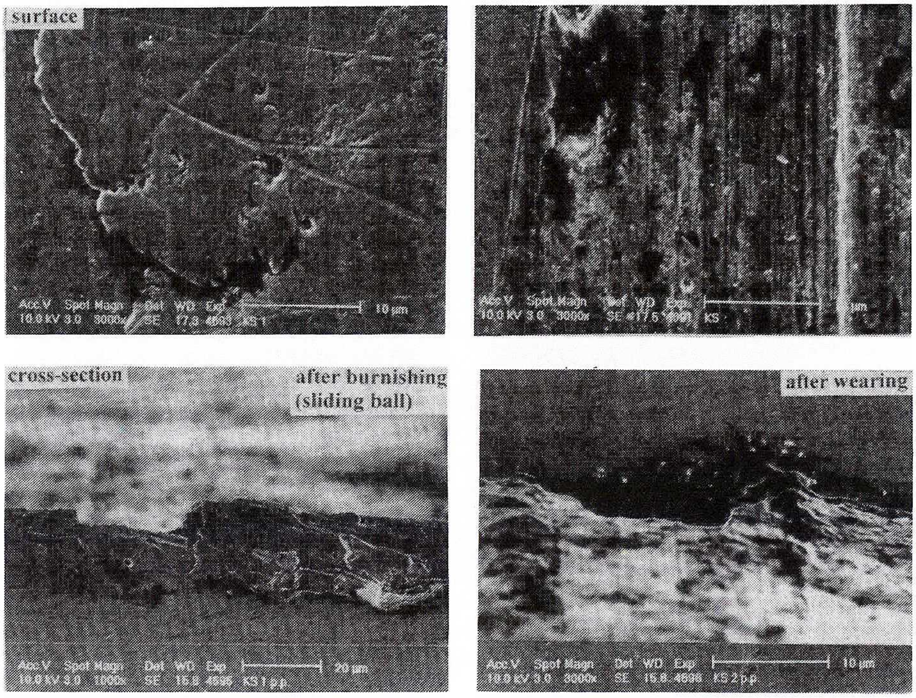

Fig. 5. Microstructure SEM of sample after burnishing by sliding ball (left) and after wearing (right); surface (a); cross-section (b)

sample previously hardened by burnishing. Regular boundaries between the subsequent burnishing tracks are visible in Fig. 3 in the case of the rolling ball. These boundaries change their character to a wavy type for the rolling mill (Fig. 4). For the sliding ball, ellipsoidal islands are visible (Fig. 5). In this case after hardening, even microcracks can be observed on the surface (Fig. 5 cross-section). The microstructure of samples after the subsequently applied wear test is similar independently of the former type of burnishing (Figs. 3–5 right side). Evident traces characteristic for the heavy deformation are visible in microstructure of the surface as well as of the cross-section of the examined samples. Results of texture examinations are presented in Fig. 6a, b, c. The identified type of the texture was very similar for the burnishing by the rolling ball or rolling mill (Fig. 6a, b).

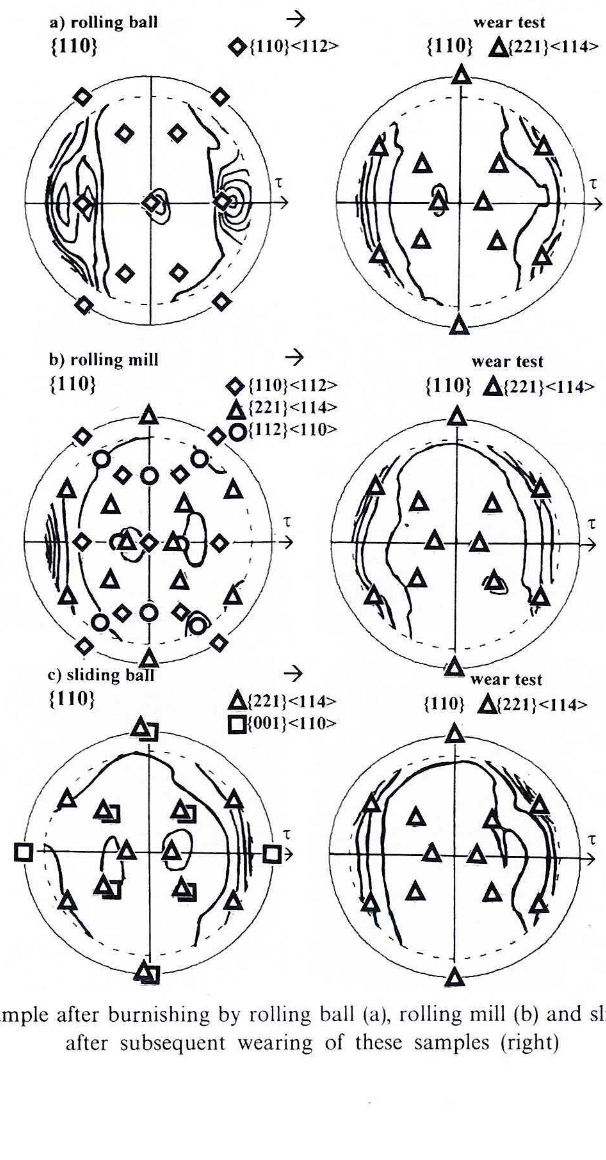

Fig. 6. Texture of sample after burnishing by rolling ball (a), rolling mill (b) and sliding ball (c) (left) and after subsequent wearing of these samples (right)

The dominating preferred type of orientation was the $\{110\}<112>$ in both cases, while beside this type of texture, the $\{221\}<114>+\{112\}<110>$ orientations were stated for the rolling mill (Fig. 6b). The texture in the case of sliding ball was described as the $\{221\}<114>+\{001\}<110>$ (Fig. 6c).

The similar texture of the $\{221\}<114>$ type was stated for all samples after the subjected wear test independently of the previously developed preferred orientation (Fig. 6a, b, c; right side). Verification of the results presented above on the basis of pole figures was done by the analysis of the reflection intensity of the chosen diffraction lines (Fig. 7). In such a type of examination, the intensity of the 110 reflection informs about a share in the $\{110\}$ crystallographic planes, situated parallel to the surface of the examined samples when the intensity of the 200 reflection concerns $\{110\}$ planes and the 211 planes $\{211\}$, respectively. Thus such examination can be assisted by the texture analysis. In Fig. 7, the type of texture previously identified on basis of pole figures was also marked.

It is evident that burnishing introduces a high deformation into the surface of the hardened materials so the deformation type of texture should be developed within.

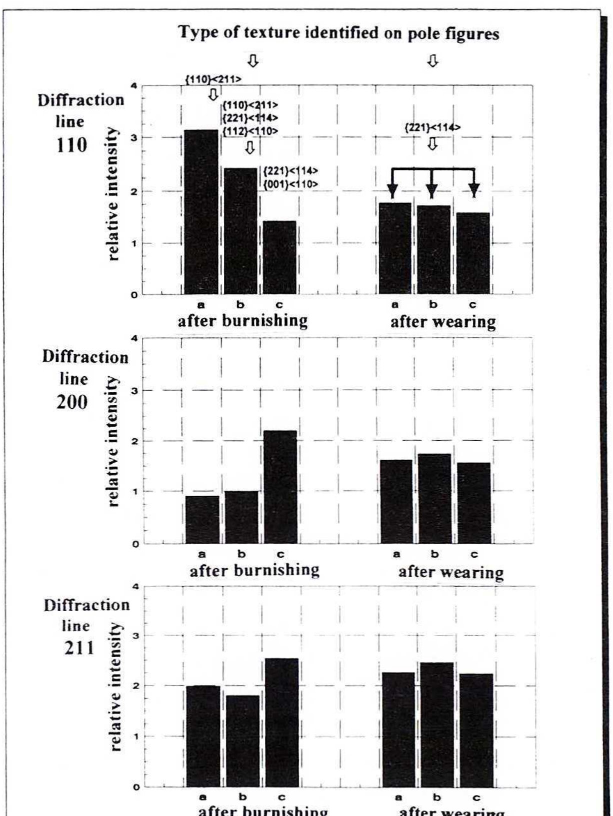

Fig. 7. Diagrams of X-ray reflection intensity measured for the 110, 200 and 211 diffraction lines

Moreover, one can searched for similarities between the rolling type of texture and the texture after the burnishing, especially in the case of rolling ball or mill on the surface of material. One can also expect a contribution of shear stresses to the deformation when the tool is sliding on the surface. The main $\{001\}<110>$ and minor $\{111\}<211>$, $\{110\}<112>$, $\{110\}<111>$ orientations are given in the literature for the b.c.c. metals and alloys as the characteristic rolling textures [10] while the $\{110\}<112>$ orientation is reported as the main shear texture of the b.c.c. metals and alloys. The later type of the shear orientation i.e. $\{110\}<112>$ has been identified in samples after burnishing using the rolling ball or mill. In the case of sample subjected burnishing by sliding ball, the $\{001\}<110>$ orientation of the rolling type has been stated. The found type of textures proves that the burnishing by means of the rolling ball or mill led to the plastic deformation realised by the shear contact deformation. The rolling type of texture observed after burning with use of the sliding ball suggested similarity of the deformation to the rolling process. The applied wear test by the dry friction revealed the similar type of the $\{221\}<114>$ texture in the samples independently of the former state. From the similarity between the observed type of texture after the wear test and the shear type of texture given in the literature for the b.c.c. materials [10] it could be concluded that the shear deformation during the wear test was dominant. The observed small differences between the measured type of the textures and the ideal shear position can be caused by the heavy deformation leading even to fracture by shearing. Such behaviour was stated in the f.c.c. materials subjected shearing [11] causing rotations from the ideal position of the f.c.c. shear type of texture.

4. Conclusions

Study of the microstructure and texture in carbon steel subjected to the burnishing can lead to the following conclusions:

1. Changes in morphology of surface layer of steel subjected to the burnishing by the rolling ball, rolling mill or sliding ball were characteristic for the heavy deformation.
2. The $\{110\}<112>$ main orientation was identified in samples after burnishing with use of the rolling ball or mill, while the $\{001\}<110>$ orientation of the rolling type was found after burnishing by the sliding ball.
3. The similarity of the texture after burnishing with use of the rolling ball or mill to the shear type of the texture proved that the burnishing by means of these types of hardening led to the plastic deformation realised by shear contact deformation while in the case of samples subjected to the burnishing by the sliding ball, the $\{001\}<110>$ orientation of the rolling type suggested deformation by compression and tension similar to the rolling process.
4. The applied wear test by dry friction revealed the same $\{221\}<114>$ type of the shear texture independently of the former state.

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