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Magnetic Evaluation of Residual Stresses and Structure Transformations Induced in Soft Steel after Turning

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This paper deals with the stress and temperature induced microstructure transformations in a soft bearing steel 100Cr6 after turning operation. Investigation is carried out through a technique based on Barkhausen effect. Evaluation of surface integrity via structure transformations, X-ray diffraction as well as microhardness inspection is carried out as well. Surface integrity is investigated with the respect to the variable tool wears and consequent mechanical and thermal loads applied on the inspected surfaces. Different surface microstructures caused by the mechanical and associated thermal aspects of the surface formation are discussed and correlated with the parameters obtained from the measured Barkhausen emissions.

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1. Introduction

Cyclic magnetic pulsation in ferromagnetic materials results into irreversible Bloch Wall (BW) motion in the form of discrete jumps well known as Barkhausen noise (BN). BN techniques are usually adopted for monitoring surface integrity of parts loaded near their physical limits. It is well known that BW motion is affected by stress state as well as microstructural features such as dislocation density, grain size, carbide precipitations, other phases and lattice imperfections [1]. Being so, the emitted BN signal carries information about interference of BW with these pinning sites. BW has to overcome the potential energy of the pinning sites during the cyclic magnetization. Moorthy [2] reported that microstructural features affect the pinning strength and the mean free path of the BW displacement while stresses affect mainly the domain alignment with respect to the stress direction. Although, BN systems are mostly used for detection of grinding damage on hardened steel surfaces, BN methods can be also applied for optimization of the whole technological process.

Deformations of parts, made of thin wall, during the hardening have a high industrial relevance. Industrial and also laboratory investigations reported that deformations of parts correlate with surface integrity of the parts before hardening, expressed in BN values [3]. It means that alteration of surface microstructure and stress state during the machining process results into variable deformations, despite keeping constant cutting conditions.

The flank wear of applied tools takes a significant role since the surface integrity is a result of processes in the tool – workpiece contact. Due to a cutting edge radius as well as flank wear VB (VerschleissmarkenBreite) a certain layer of material undergoes the cutting edge as indicates Fig. 1. Mechanical and thermal exposure of undergoing layer depends on cutting conditions, tool geometry, machined material and flank wear since flank wear determines the path (and corresponding time) during which the produced surface is under the severe plastic deformation state. This paper focuses on the influence of VB on the surface integrity, expressed in BN features and additional techniques.

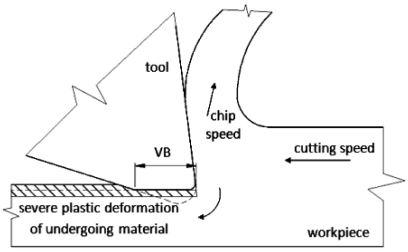

Fig. 1. Plastic deformation of undergoing material.

2. Experimental part

Experiments were carried out on the roll bearing steel 100Cr6 before heat treatment (rings of diameter 52 mm and width of 20 mm). Five inserts of the different flank wear VB (0.05; 0.2; 0.5; 0.65 and 0.9 mm) were prepared before the test, through the long-term preliminary stage of experiment.

Cutting insert: SNMG 120408E-M 6630, $a_p = 1$ mm, $f = 0.09$ mm, $v_c = 100$ m·min^{-1}. The BN signal (effective rms value) was measured in the 8 points on the ring periphery by use of the Rollscan 300 and processed by MicroScan software package (mag. frequency 125 Hz, mag. voltage 5 V, sine shape, analyzed frequency band 70 – 200 kHz). Residual stresses were measured via X-ray diffraction technique ({211}, CrKα, X'Pert PRO). Vickers microhardness measurement was conducted by Hanneman micro-hardness tester by applying force of 300 N for 10 seconds.

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The structure alterations occur when VB exceeds 0.5 mm. While very thin and discontinuous transformed layer with significant texture can be found on the surface produced with insert of VB=0.65 mm (Fig. 2b), more pronounced structure transformation occurs when flank wear reach 0.90 mm (Fig. 2c). Surface texturing is associated with intensification of plastic deformation of the undergoing layer together with the longer time interval of surface exposure.

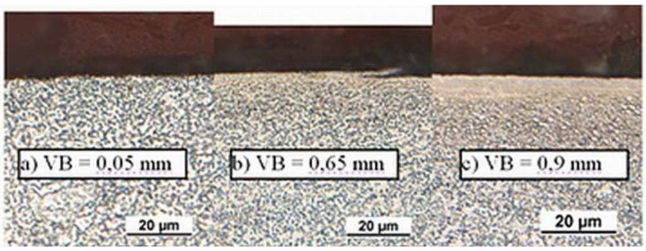

Fig. 2. Micrographs of machined surfaces, Nital 2%.

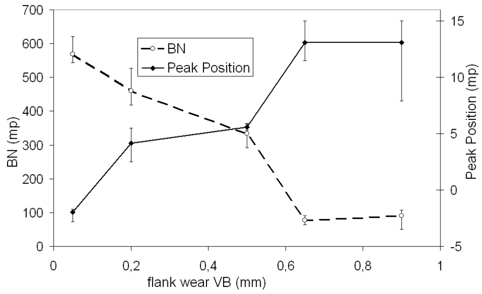

Fig. 3. BN and Peak Positions versus flank wear VB.

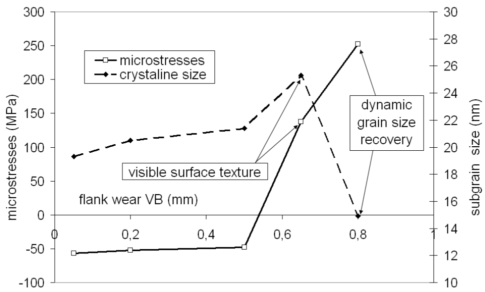

Fig. 4. Microstresses and sub grain size versus flank wear VB.

It was previously discussed [4] that cutting forces and temperature in the cutting zone gradually increase up to the VB=0.65 mm with a certain fall when the visible structure transformations on the produced surface can be observed (VB=0.9 mm). Intensification of plastic deformation with flank wear is connected with the increas of dislocation cell density which hinders BW motion and corresponds with the decrease of BN values as well as the shift of the "peak position" parameter extracted from the raw BN signal (Fig. 3).

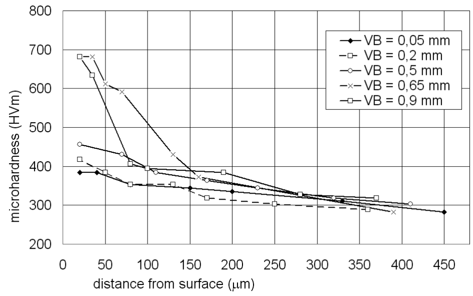

Fig. 5. Microhardness profiles.

The shift of peak position means that higher magnetic field is needed for BW motion. Figure 3 also illustrates saturation of both quantities as soon as flank wear reaches 0.65 mm. Further increase of flank wear and corresponding mechanical and thermal load does not induce higher density of dislocation cells. Plastic deformation of the surface reaches the critical limit and dynamic recovery occurs. Indicated information corresponds with the microstresses and sub grain size shown in Fig. 4. Only a gentle increase is found on the surfaces without visible texture or structure transformation. More pronounced elongation of grains contributes to the increase in sub grain size when only visible surface texture is observed. When the dynamic recovery takes place, the steep decrease of sub grain size and increase of microstresses is associated with the new configured fine grain structure on the near surface.

The hardness of steels is due to high dislocation density while the carbide precipitation takes the minor role. The measured profiles (Fig. 5) correlate with microstructure observations, BN values and measured microstresses.

While moderate increase of the surface microhardness is attributed to the surfaces without visible structure transformations and high magnetoelastic responses, the steep increase of the near surface hardness correlates with the low BN values due to high pinning strength of hardened structure containing high dislocation density.

Acknowledgments

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