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Magnetic Anisotropy in Case-Carburized Surfaces after Hard Turning

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This paper deals with magnetic anisotropy found in hard turned surfaces. The high magnetic anisotropy of the surface after hard turning operations occurs due to severe plastic deformation and high temperature, exceeding the Curie temperature in the cutting zone, followed by rapid cooling. The transformed microstructures of the surface, and stress anisotropy near the surface cause the magnetic anisotropy and magnetic domain reconfiguration. On the contrary, temperatures during grinding usually do not exceed Curie temperature and so the remarkable magnetic anisotropy after grinding operations in not found. The magnetic properties of the studied surfaces are analyzed by Barkhausen noise emission as well as magneto-optical methods. The results of these two techniques are used to study the magnetic anisotropy.

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1. Introduction

Grinding process is sometimes replaced with hard turning operation. Grinding is a process, when very fine chips are produced as a result of hundreds of interactions of small grinding grains with workpiece. Hard turning is a process when only one massive chip is separated. To compare between hard turning and grinding it can be found that contact length between tool and workpiece and time for heat conduction are much longer during grinding. For this reason, grinding operations can suffer from thermal softening of the ground surface, which is associated with higher Barkhausen noise (BN) values [1]. When the surface hardness decreases, the thickness of heat-affected zone (HAZ) extends, and residual stresses are shifted towards tensile stresses [2]. Steels and other materials are heat treated to impart good wear and frictional resistance associated with high hardness. High hardness of surface results in poor BN values [3]. On the other hand, very high heating rates and rapid cooling during hard turning generate the specific state of surface integrity expressed in many terms. Very high BN values and strong magnetic anisotropy can be found on the surface despite limited structure transformations and high hardness. Being so, these aspects should be explained to develop a reliable concept based on BN for monitoring of surfaces after hard turning.

2. Experimental part

The experimental study was carried out on case-carburized and hardened steel AISI 3412 (61 HRC). To investigate the ground surfaces of the different state, wet ground surface is compared with the surface ground without coolant supply (dry grinding). Conditions: grinding A9880J9V $v_c = 25$ m·s^{-1}, $v_p = 0.003$ mm per rev.; turning – v = 150 m·min^{-1}, $a_p = 0.5$ mm, $f = 0.2$ mm, round ceramics inserts ($\gamma_n = 0°$).

BN technique was carried out with Microscan 500 (mag. voltage 10 V, mag. frequency 125 Hz, sine profile). Residual stresses were measured via X-ray diffraction technique ({211} , α-Fe, CrK$_\alpha$, X'Pert PRO). Tangential measurement of residual stresses and BN correspond with direction of cutting speed while axial measurements were carried out in the perpendicular direction. The surfaces have been also observed using magneto-optical Kerr effect microscope.

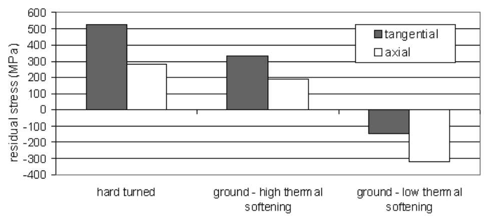

Fig. 1. Residual stresses measured via X-ray diffraction technique.

The measured residual stresses presented in Fig. 1 indicate strong relation among stress state of investigated ground surfaces, microstructural features and corresponding BN values shown in Fig. 2. The explanation of higher BN values after grinding is connected with more pronounced thermal softening, which influences the microstructure and stress state in a synergistic manner [3]. While limited thickness of HAZ (up to 10 μm – nearly untouched surface with the discontinuous dark spots, indicated in Fig. 3b) can be found after wet grinding, the dry grinding process produces the surface with extended thermal softening exceeding 70 μm (dark layer of variable thickness depicted in Fig. 3c).

Figure 3 is a compilation of three micrographs where thermal softening in the case of grinding can be indi-

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cated as the dark zone clearly distinguished from the untouched bulk structure below. This figure also indicates the corresponding BN_T values measured in the tangential direction.

When limited thermal load of ground surface is obtained (Fig. 3b), the microstructure is dominated by high dislocation density, the carbide precipitates and the paramagnetic retained austenite phase, which are strong obstacles to Bloch Wall (BW) motion. The thermal softening (Fig.3 c) enhances BW motion due to the decrease of dislocation density, coarsening of carbide precipitates and transformation of paramagnetic austenite to martensite. Temperature during grinding usually does not exceed critical temperature of austenite transformation. The absence of a white layer on the ground surface illustrated in Fig. 3b,c, indicates that no transformations are induced either by wet or dry grinding. Residual stresses are shifted towards the tensile zone and also contribute to the higher BN values.

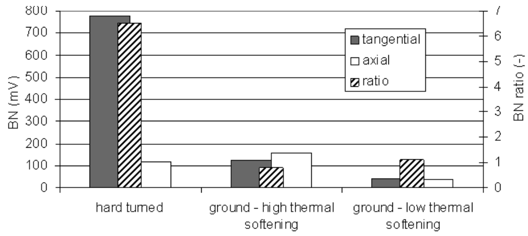

Fig. 2. BN values and their ratio for different surfaces.

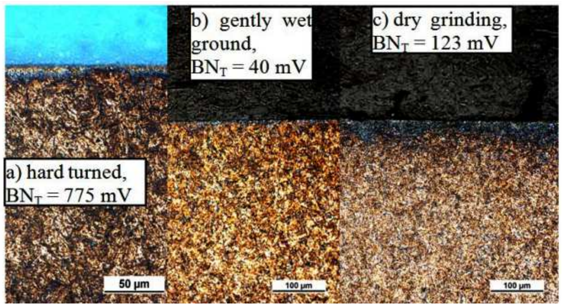

Fig. 3. Micrographs of machined surfaces, Nital 5%.

Thermal softening during hard turning is reduced and thickness of HAZ is low as Fig. 3a illustrates (white layer of thickness up to 10 μm). Therefore, the high BN_T values for hard turned surface can not be attributed to the microstructural feature alteration. Furthermore, high tensile stresses found on the hard surface can not fully explain extremely high BN values. Temperature in the cutting zone takes key role.

Hard turning initiates high temperatures and superimposing hydrostatic pressure ahead the cutting edge. These cause that the hard and brittle structure is behaving in a malleable manner. Temperature in the tool–workpiece interface exceeds the Curie temperature [4] needed to disturb domain configuration of ferromagnetic steel. During hard turning the restricted tool – workpiece interface area and the superimposing fast heating up and rapid cooling rates allow only limited structure transformations (Fig. 3a). The domain configuration of the near surface layer is disturbed above the Curie temperature. New domain alignment is configured during rapid cooling with preferentially oriented domains in the direction of the cutting speed due to stress anisotropy and magnetostriction.

A certain idea about anisotropy is indicated in magneto–optical Kerr micrographs (Fig. 4). The high BN values of hard turned surface in the tangential direction are associated with the specific domain arrangement. The magnetic anisotropy, expressed in term of different BN values (Fig. 2), is connected with domain reconfiguration.

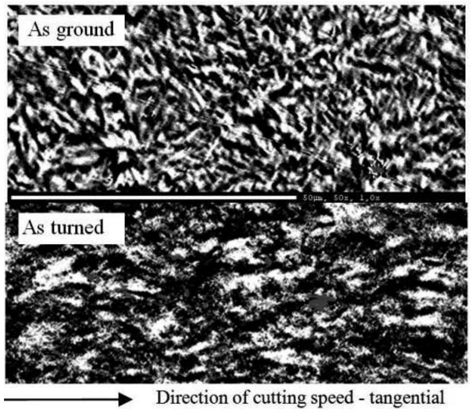

Fig. 4. Magnetooptical Kerr micrographs of surfaces.

3. Conclusions

The stress anisotropy is found on all machined surfaces. However, the corresponding magnetic BN anisotropy is found only on hard turned surface. This suggests that the temperature in the cutting zone, exceeding the Curie temperature, is a key factor. Despite the fact that the affected surface layer after the hard turning is very thin (up to 10 μm - compared to the skin-depth about 125 μm), this near surface zone considerably contributes to very high BN values.

Acknowledgments

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References

[1] V. Moorthy, B.A. Shaw, P. Hopkins, *J. Magn. Magn. Mater.* **299**, 362 (2006).

[2] M. Rosipal, *Ph.D. Thesis*, University of Žilina, 2012.

[3] M. Vashista, S. Paul, *J. Magn. Magn. Mater.* **323**, 2579 (2011).

[4] J.Y. Wang, C.R. Liu, *CIRP* **48**, 53 (1999).