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Procedia Materials Science 12 (2016) 60 – 65

Procedia Materials Science

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6th New Methods of Damage and Failure Analysis of Structural Parts [MDFA]

Concept of Damage Monitoring after Grinding for Components of Variable Hardness

A. Mičietová[a]*, J. Pištora[b], Z. Durstová[a], M. Neslušan[a]

[a]*University of Žilina, Faculty of Mechanical Engineering, Univerzitná 1, 010 26 Žilina, Slovak Republic*
[b]*VŠB – Technical University of Ostrava, Nanotechnology Centre, 17. listopadu 15, 708 33 Ostrava – Poruba, Czech Republic*

Abstract

This paper deals with nondestructive magnetic evaluation of ground surfaces of chosen material hardness. The properties of prepared surfaces are studied with respect to the progressively worn grinding wheel. The nondestructive testing is based on the Barkhausen noise (BN) technique and obtained BN signals are supplemented by metallographic observations. The results show that the nature of thermal injury of the surfaces prepared by strongly worn grinding wheel significantly depends on the hardness of material. The typical thermal softening induced by grinding cycle is found on the surfaces of hardness 62 HRC whereas samples of lower hardness exhibit rehardening effect associated with the formation of white layer. These material changes are strongly correlated with the BN properties.

Selection and peer-review under responsibility of the VŠB - Technical University of Ostrava,Faculty of Metallurgy and Materials Engineering

Keywords: bearing steel; heat treatment; grinding; Barkhausen noise

Nomenclature

BN	Barkhausen noise	HRC	Rockwell C hardness
BW	Bloch wall	PP	Peak Position
WL	white layer		

* Corresponding author. Tel.: +421-41-51-2781; fax: +421-41-565-2940.
E-mail address: anna.micietova@fstroj.uniza.sk

Selection and peer-review under responsibility of the VŠB - Technical University of Ostrava,Faculty of Metallurgy and Materials Engineering
doi:10.1016/j.mspro.2016.03.011

1. Introduction

Roll bearings are routinely heat treated in a variety of manners. Except induction or case-hardening, conventional heat treatment is carried out to impart the high hardness and the corresponding high resistance against friction and contact wear. Annealing process is always performed after hardening to reduce the high internal stresses induced during rapid cooling. Additional heat treatment is sometimes required to enhance the toughness of hardened parts. These parts are exposed to the elevated temperatures for a certain period within hardness of parts decreases as a result of carbides coarsening, decrease of dislocation density and stress relaxation. Hardness of such parts can vary in the range 38 to 62 HRC.

Grinding operations are usually involved in production of bearings to achieve the required surface roughness, shape and dimension accuracy. Nowadays, alterations of surface structure, hardness or stress state are also monitored due to its substantial influence on functionality of parts in operation.

Non-destructive monitoring of critical surfaces has to be carried out to reveal the parts containing the unacceptable surface integrity. Magnetic method based on BN is very often employed for such purpose, especially ground surfaces due to the high sensitivity of BN emission to the thermally induced surface overtempering, Moorthy (2001) and Čiliková (2013). As widely discussed by Moorthy (2001), Karpuchewski (2002), Kameda and Ranjan (1987), Buttle (1991), Gatelier-Rothea (1998) and Ranjan (1987) BN originates from irreversible BW motion during cyclic magnetization due to existence of pinning sites such as grain boundaries, dislocations, precipitates, other phases. Ground parts can suffer from thermally induced burn as a result of excessive heat generation in the wheel – workpiece contact. Being so, Moorthy (2001), BN emission increases in magnitude due to decreased pinning strength of thermally softened layer produced by improper grinding as a result of carbides coarsening and decrease of dislocation density (stress state is also altered). Thermally softened layer contributing to the more enhanced BN signal received on the frees surface layer can be easily contrasted and recognized when compared with untouched deeper regions in an optical image due to reduced resistance against etching Čiliková (2013).

Concept for monitoring of surface damage after grinding is based on the contrast between BN emission of untouched structure and altered BN response (its root mean square value) of the surface undergoing the elevated temperatures, Čiliková (2013), Moorthy (1998) and Čiliková (2014). On the other hand, such concept can fail when the hardness of a component decreases. Then the overtempering effect induced by grinding is shadowed by the previous heat treatment regime since the both processes represent nearly the same thermal load of the surface. BN emission and its evolution depend on the annealing temperature and the temperature in wheel – workpiece contact. The higher annealing temperature is, the less pronounced contribution of the surface overtempering induced by grinding itself would be expected which in turn corresponds to the less remarkable contrast between the deeper untouched and the near surface thermally softened layer. Critical components are usually heat treated to impart quite high surface or/and core hardness. Ground surfaces of such components can be easily monitored when BN technique is employed.

Nowadays, industry customers require employment of BN or other non-destructive techniques to reveal the unfavourable surface state on components of variable hardness. Being so, manufacturers tend to modify the techniques already available in their production for additional applications, surfaces and components made of the variable hardness. These modifications rely on the deep understanding of between the surface properties and the measured BN signal. The properly suggested concept, which implementation would bring the substantial benefits, can be based only on the true interpretation of received signals and their correlation with surface integrity expressed in terms of stress state and microstructure.

This paper represents the initial study in which the evolution of BN and the BN features versus progressive grinding wheel wear for components of variable hardness is investigated. This paper discusses the specific aspects of the surfaces machined on the bearing steel heat treated on selected hardness. Surface characterization is determined by BN technique as well as the conventional ones such as metallographic observation.

2. Conditions of experiments

The experiments were carried out in the laboratory conditions on samples in the form of ring made of 100Cr6 bearing steel of hardness 62HRC, 45HRC and 40HRC (55 mm - outer diameter, 41 mm - inter diameter, 12 mm in width). The rings were heated on austenitizing temperature 840ºC and quenched in the oil of temperature 70ºC. Then the rings of hardness 62 HRC were annealed at temperature 180 ºC for 2 hours (rings of hardness 45 HRC were annealed at 530ºC and rings of hardness 40 HRC at 580 ºC for 2 hours).

Three series of 40 rings (each of the different hardness) were consequently wet ground to facilitate a certain grinding wheel wear and the corresponding thermal load of the ground surface. Grinding wheel was redressed before each series by the use of single crystal dresser a_{ed} = 20 µm, v_{cd} = 25 m.s^{-1}, v_{fd} = 90 mm.min^{-1}. Ecocool type coolant of 3% concentration was used: Q_f = 12 l.min^{-1}, shoe nozzle. During the process the wear of the grinding wheel have been rising gradually with the order number of the ring in a series. Cutting conditions as follows: v_c = 30 m.s^{-1}, v_p = 0,01 mm.s^{-1} and v_f = 11 m.min^{-1}. Grinding wheel: 350x50x127, A98 80 J9V, machine tool 2uD P27 50. Rough and finishing grinding stock 0,3 mm.

BN measurements have been performed by the use of Rollscan 300 and software package Microscan in the frequency range 70 to 200 kHz (mag. frequency 125 Hz, mag. voltage 10 V). Each ring was measured in 4 points in the center of a ring width. BN values were determined by averaging of 10 consecutive bursts (5 magnetizing cycles) at 4 measuring points. BN values in this study represent the effective (rms) value of the received signal.

10 mm long pieces were sectioned from the rings and routinely prepared for metallographic observations. Microstructures were observed in the center of the ring width to match the positions of metallographic observation with positions where BN were measured. Residual stresses were measured by the mechanical method based of etching of ground surface and simultaneous measurement of a ring deformation.

3. Experimental results and discussion

Fig. 1. illustrates the evolution of BN values along with the progressively developed grinding wheel wear corresponding to the number of consequently ground rings. This figure demonstrates that thermal softening dominates in grinding surface of hardness 62 HRC and progressive increase of BN is due to enhanced BW motion attributed to the weaker pining strength of thermally softened layers (decrease of dislocation density, coarsening of carbides and tensile stresses, Moorthy (2001) and Moorthy et. al. (1998).

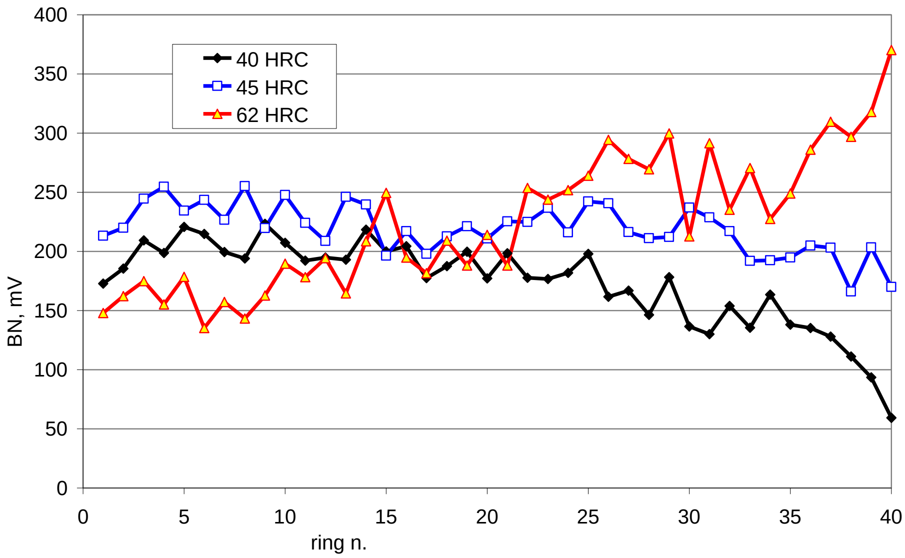


Fig. 1. Evolution of BN for samples of variable hardness.

On the other hand, evolution of BN values versus grinding wheel wear for surfaces of hardness 40 and 45 HRC differ from the abovementioned case. BN values stay nearly untouched in the initial grinding cycles with the following more or less remarkable progressive decrease. However, the highest BN values for 45 HRC found in the early grinding cycles are quite controversial when compared to 40 HRC samples.

Decrease of BN and the corresponding increase of PP, see Fig. 2., indicate that surface hardening dominates in such surface. Fig. 1. indicates that surfaces of hardness 45 HRC expressed in term effective (rms) BN value are less sensitive to the thermally induced processes in the wheel - workpiece contact. Being so, additional BN features should be employed for detection of surface damage induced by grinding. It seems that PP more properly corresponds to the progressive increase of thermal load.

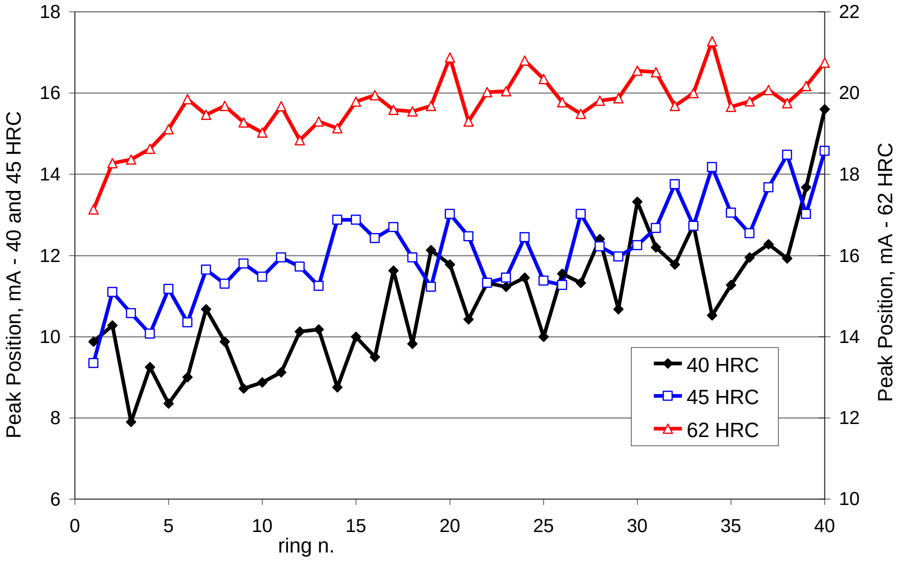
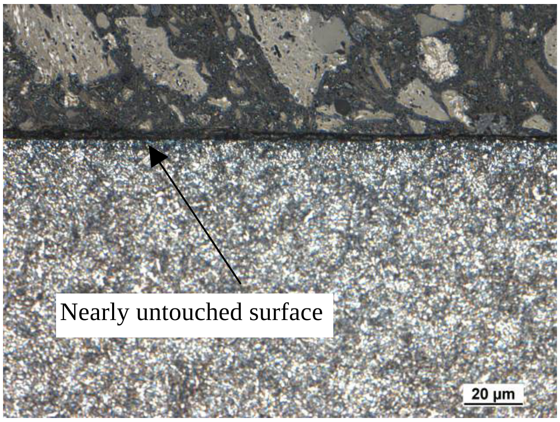


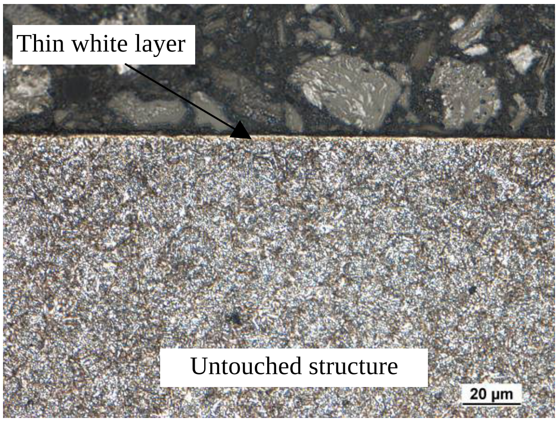
Fig. 2. Evolution of PP for samples of variable hardness.

Fig. 2. shows that the shift of the PP towards higher magnetic field is a general property of the bearing steel of all used hardness. Surfaces made of hardness 62 HRC bearing steel exhibit remarkable increases in PP only in the early phases of grinding cycles and stay nearly untouched afterwards. Intuitively high PP indicates hard structure of high pinning strength in which BW is hard to unpin, Bayramoglu et. al. (2010) and Čiliková et. al. (2014). In Fig. 2. it is shown that high mechanical hardness of 62 HRC corresponds with the high PP whereas the low hardness of 45 and 40 HRC is connected with lower one. Such behaviour has not been discovered yet but it is considered that a specific structure constituent does not contributes to the structure hardness but pin BW motion, thus increases PP.

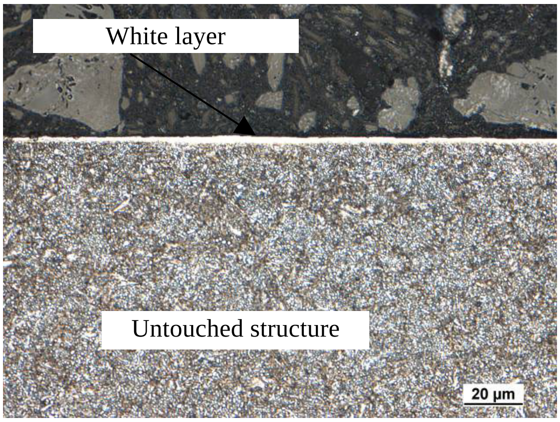
The micrograph Fig. 3a of grinded surface prepared on the 40 HRC steel does not reveal visible structure alteration due to shadowing effect of the previous heat treatment. It indicates that grinding process in such case exposes the ground surface nearly the same temperature as that during annealing process at elevated temperature (about 580ºC). Further increase of temperature in the wheel – workpiece interface results in formation of WL as a product of rehardening effect, see Fig. 3b,c,d. The near surface region undergoes heating above the austenitizing temperature followed by rapid self-cooling.



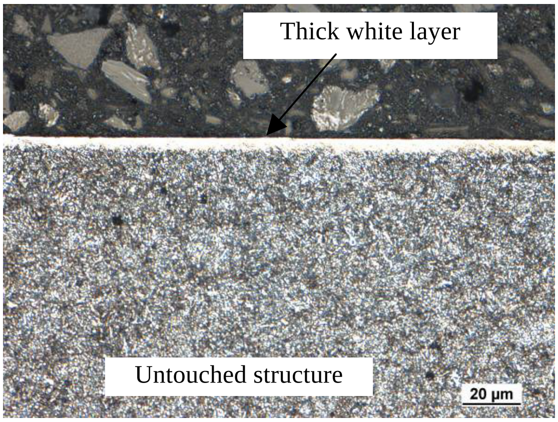
a) ring n. 1, 40 HRC, BN = 172 mV



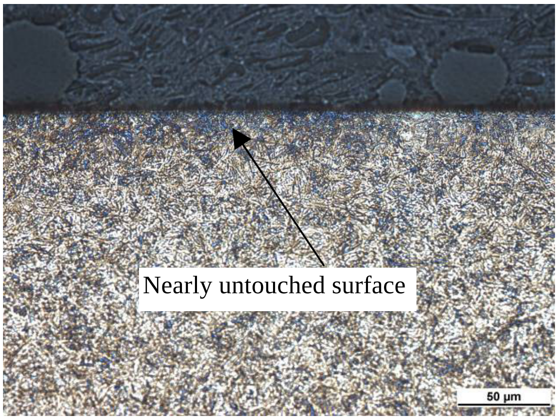
b) ring n. 26, 40 HRC, BN = 162 mV



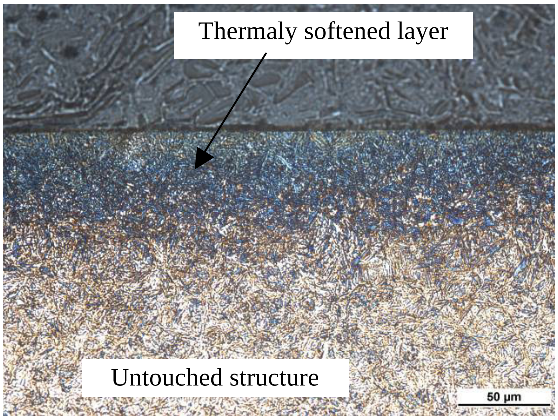
c) ring n. 39, 40 HRC, BN = 94 mV



d) ring n. 40, 40 HRC, BN = 59 mV



e) ring n. 2, 62HRC, BN = 162 mV



f) ring n. 22, 62HRC, BN = 253 mV

Fig. 3. Micrographs of ground surfaces

4. Conclusions

The properties of ground surfaces with respect to the material hardness and the grinding wheel wearing are studied in this paper. It is shown that the microstructure of affected surfaces strongly depends on the hardness of the material. The surface of hard material is thermally softened, while rehardening effect associated with the formation of white layer is typical for soft bearing steels with the hardness below 50HRC.

The properties of Barkhausen noise are strongly correlated with the surface microstructure. The most significant is the relationship between the surface hardness and BN amplitude which is rapidly decreasing with the progress of rehardening process and rapidly increasing in the thermally softened surface. The PP of the BN bursts is shifted to the higher magnetic fields as the tool wear is progressing.

This study demonstrates that conventional concept employed for detection of grinding burn cannot be used in general for bearing steels of all hardness. The BN amplitude dependence on the grinding wheel wearing must be calibrated separately for each machined material. The BN methods are not applicable on the steels where the impact of rehardening effect is compensated by the thermal softening in deeper region.

Acknowledgements

The authors gratefully acknowledge the support by Vega project n. 1/0097/12 and by the Centre of Excellence IT4Innovations project, reg. no. CZ.1.05/1.1.00/02.0070.

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