Influence of Tool Wear on Surface State after Turning Stainless Steels

Miroslav Neslušan[1], Mária Čilliková[1], Anna Mičietová[1], Jiří Čapek[2]
[1]Faculty of Mechanical Engineering, University of Žilina, Univerzitná 1, 01026 Žilina, Slovak Republic, e-mail.: miroslav.neslusan@fstroj.utc.sk
[2] Faculty of Nuclear Science and Physical Engineering, ČVUT Praha, Trojanova 13, 120 00 Praha 2.

This paper deals with influence of tool wear on surface integrity after turning of stainless steels. Surface integrity is expressed in terms of structure transformation initiated by turning process as well as Barkhausen noise emission. Furthermore, components of cutting forces are also measured as a function of tool wear and their evolution along with developed flank wear VB is presented. The results indicate that presence of carbides in the matrix – their size and density play a significant role in the resistance of the matrix against the structure transformations. The results also indicate that Barkhausen noise technique is sensitive to structure transformations of austenite steels initiated by turning process.

Keywords: Turning, Structure, Stainless Steel, Barkhausen Noise

1 Introduction

Machining operations performed on components can remarkably affect surface integrity expressed in many terms. Except shape aspects expressed in terms of components precision, deviations of shape, surface waviness or surface roughness also alterations of mechanical and other properties should be considered. These aspects are usually expressed in terms of residual stresses, structure transformations, alterations of micro hardness, etc. and should be carefully investigated due to their significant role in components functionality [1, 2].

Stainless steels are widely employed in many industrial applications due to their outstanding resistance against corrosion or high strength. On the other hand, machining of these materials could be cost demanding due to reduced cutting speeds, longer cutting time cycles or more intensive tool wear. Production of components made of stainless steel (but generally made of any material) is usually performed at constant cutting and other conditions. However, such aspect as tool wear is progressively developed during machining. Tool wear progressively transforms tool geometry with in turn alters mechanical and thermal load of machined surface. Intensity of mechanical and thermal load increases along with more developed flank wear *VB*. On the other hand, increasing *VB* also makes longer time period during which machined surface is exposed to the mechanical and thermal load. Being so, surface state of components made of any materials can vary and some components could be found as unacceptable. Especially components made of stainless steels could be sensitive to the above mentioned process. Being so, this paper investigates influence of tool wear on cutting forces and microstructure of chosen stainless steel.

One of the possible techniques suitable for monitoring surface integrity from the point of view of structure transformations is Barkhausen noise (BN) emission. BN signal originates from irreversible and discontinuous Bloch Walls (BWs) motion during which produces electromagnetic pulses. These pulses can be detected on the free surface. BN originate only from ferromagnetic bodies. For this reason any transformation from austenite to ferrite can be easily and reliable detected. BN is sensitive to the structure alterations as well as stress state. More details can found in literature [2, 3, 4]. BN technique is frequently adapted for monitoring machining cycles [2 - 7] but its application for turning stainless steels has not been discussed yet. Thus this paper bridges this gap.

2 Experiments and method

Tab. 1 *Chemical composition of machined samples - expressed in wt. %*

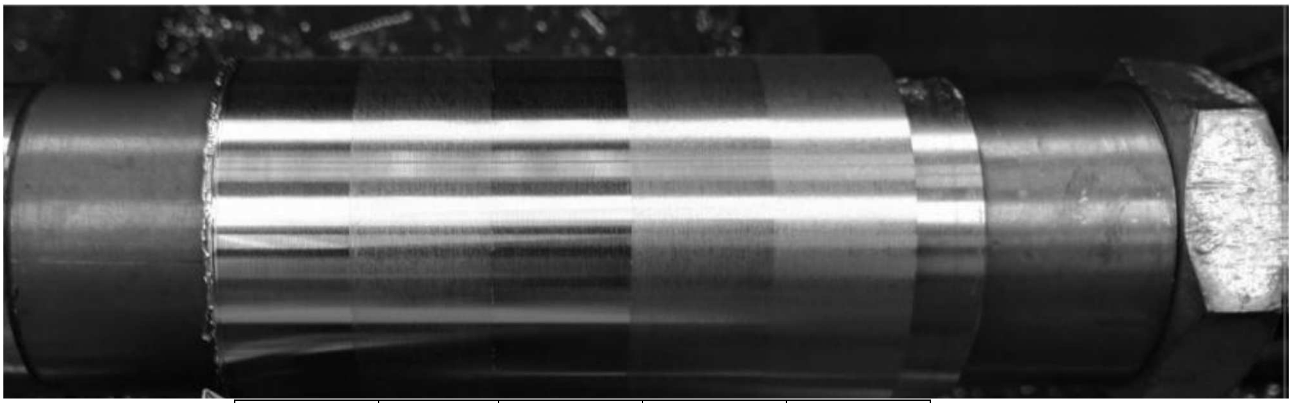
	C	Si	Mn	P	S	Cr	Ni	Cu	Mo
41 2050	0.432	0.180	0.700	0.021	0.025	0.027	0.170	0.270	0.040
41 7140	0.116	0.330	1.140	0.024	0.306	16.750	-	-	0.220
41 7240	0.026	0.380	1.280	0.035	0.027	18.160	8.020	0.570	0.310
41 7243	0.053	0.431	1.692	0.030	0.286	17.121	8.265	0.478	0.335
41 7349	0.020	0.510	1.510	0.029	0.026	16.850	10.040	-	2.010

Experiments were carried out on 5 steels, 4 stainless steels as well as conventional steel 412050.3 of stainless steels were non ferromagnetic and 17140 was ferromagnetic steel. Their chemical composition is indicated in Tab. 1, materials equivalents according the different standards are presented in Tab. 2.

Experiments were carried out on lathe SUI 40 and samples of external diameter 60 mm, inner diameter 40 mm and width 15 mm clamped on the common shaft and turned as one tool pass over all samples, see Fig. 1. 5 cutting inserts SNMG 120408E-M with the different flank wear *VB* (0.05mm; 0.2mm; 0.5mm; 0.65mm and 0.9mm) were prepared prior turning in the preliminary phase. Cutting forces were measured by the use of three component piezoelectric dynamometer KISTLER. The signal was sampled by frequency 1000Hz and filtered afterward. Cutting conditions: v_c = 100 m.min^{-1}, f = 0.09 mm, a_p = 0.5 mm, dry machining.

Tab. 2 *Equivalents of materials*

CSN/STN	DIN	AISI	ISO
41 2050	1.1191	1045	C45
41 7140	1.4104	430F	X14CrMoS17
41 7240	1.4301	304	X5CrNi18-10
41 7243	1.4305	303	X8CrNiS18-9
41 7349	1.4404	316L	X2CrNiMo17-12-2



41 7349	41 7243	41 7240	41 7140	41 2050
feed speed ←				

Fig. 1 *Placement of rings on the common shaft*

BN measurements were performed by the use of Rollscan 350 device and software package µScan in the frequency range of 10 to 1000 kHz (magnetizing frequency 125 Hz, magnetizing voltage 10 V). BN values were obtained by averaging 10 BN bursts (it means 5 magnetizing cycles). BN signal was measured in the direction of cutting speed. BN value refers to the effective parameter of the obtained BN signal. All the samples were measured before turning. All non ferromagnetic samples emitted zero BN signal since BN signal in the range from 25 to 30 mV originates from measuring system.

Samples of length approx. 15 mm were cut from the rings after cutting and routinely prepared for metallographic observation (hot moulded, ground, polished and etched for 10 seconds). Metallographic observation was carried out in the direction of cutting speed.

3 Results of experiments

Fig. 2 and Fig. 3 illustrate the typical records of cutting forces during turning of steels with the different tool wear whereas the Fig. 4, Fig. 5 and Fig. 6 represent the cumulative information about evolution of all components along with developed flank wear *VB*. All these figures indicate that differences among the steels for the low degree of *VB* are quite small and become more remarkable as soon as the flank wear progressively increases. All components for all steels increase with increasing *VB*. However, quite low differences were found for F_c components. On the other hand, flank wear remarkably alters tool geometry which becomes more negative. Being so, passive component of cutting force increases more remarkable with more developed *VB*.

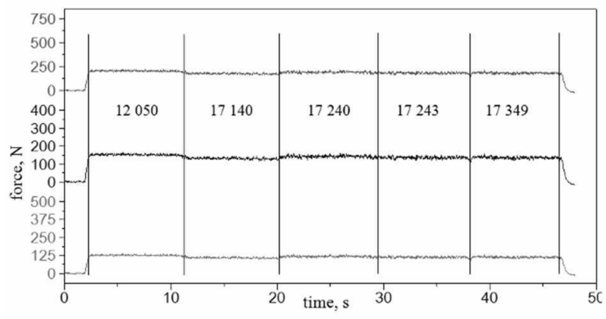


Fig. 2 *Record of cutting forces, VB = 0.2 mm, F_c – blue, F_p – red, F_f – purple, low pass filter 10 Hz*

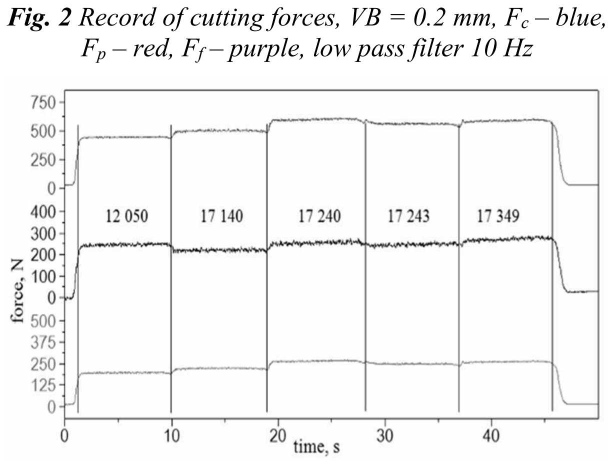


Fig. 3 *Record of cutting forces, VB = 0.9 mm, F_c – blue, F_p – red, F_f – purple, low pass filter 10 Hz*

Tangential components increases from approx. 130 N up to 250 N however the differences among the stainless steels are quite low. Low differences are associated with the fact that F_c component in this particular case (taking into consideration tool geometry and cutting condition) are attributed mainly to chip formation as a process running on the rake zone of the insert edge whereas flank wear is developed in the contact between the tool flank wear land and produced surface of the component. For this reason, increasing *VB* influences more remarkable passive component of cutting force F_p. While initial values of passive force for VB = 0.05 mm are comparable with tangential component of cutting force much higher passive components are obtained for VB = 0.65 mm or VB = 0.9 mm. Also differences among the steels become more remarkable as soon as the flank wear is more developed. The same character of evolution of cutting force components (compared to F_p) can be found for axial component F_f, see Fig. 6. Lack of proportionality, in which the different components of cutting force develops along with increasing flank wear *VB*, results into increasing F_p/F_c ratio as Fig. 7 illustrates. Such observation is typical for many machining cycles.

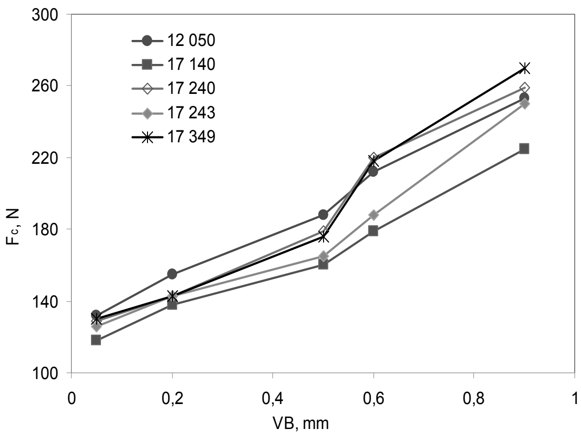


***Fig. 4** Influence of VB on F_c*

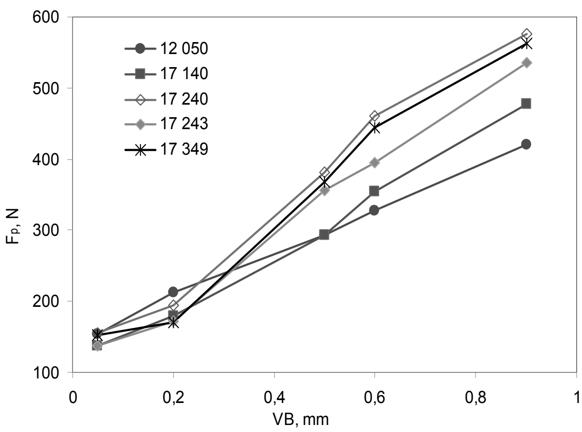


***Fig. 5** Influence of VB on F_p*

Analysis of cutting force components indicates increasing mechanical as well as thermal load in the cutting zone since cutting force refers also about the energy needed for chip separation and other process in the cutting zone. However, this energy is transformed into the heat with in turns means increasing temperature in the cutting zone. Whereas increasing temperature in the contact between tool rake and chip could be acceptable, increasing temperature in the contact between tool flank land and machined surface could initiate unfavorable structure and other transformations which in turns could lead to the for instance early crack initiation and premature failure of components. Such transformations could be especially monitored in the case of stainless steels as components exposed to the aggressive environment or/and high mechanical load.

As it was mentioned above steels made of 41 7240, 41 7243 and 41 7349 are non-ferromagnetic bodies entirely composed of austenite. Being so, structure transformations initiated cutting (or other) process can easily monitoring by BN. The scope of such measurement is based on zero BN emission before machining and comparing the BN signal as well as the effective value of BN after turning process since structure transformations of austenite bodies are usually connected with transformation of non ferromagnetic austenite to the ferromagnetic ferrite.

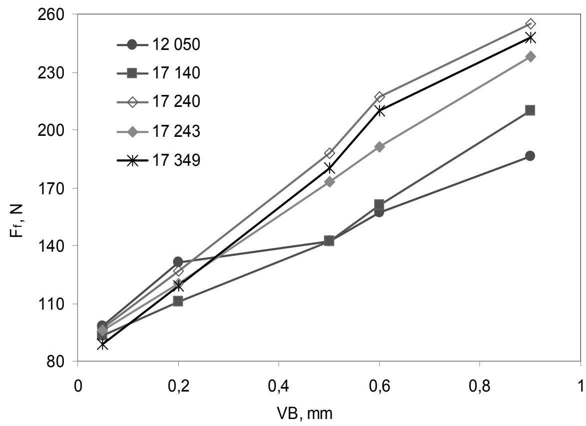


***Fig. 6** Influence of VB on F_f*

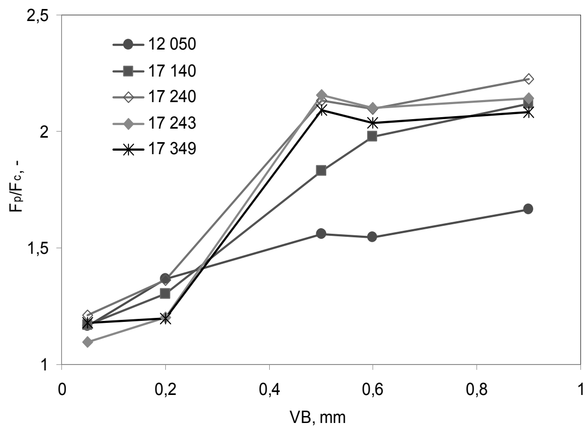


***Fig. 7** Influence of VB on F_p/F_c*

Fig. 8 shows BN signal for nearly untouched surface of steel 41 7240 produced by insert of VB = 0.2 mm (black signal). Such signal represents BN emission produced mainly RollScan system (magnetization coils) with only minor (or zero) contribution of the machined surface. On the other hand, the red signal shows remarkable increased magnitude of BN bursts for the surface produced by insert of *VB* = 0.9 mm. The other austenite steels (41 7243 and 41 7349) produces zero BN for all *VB*. The cumulative information about evolution of BN versus *VB* can be found in Fig. 11. This figure also shows that structure transformations in austenite steel 17 240 becomes more developed for highly developed *VB* (*VB* = 0.5 mm and more).

Evolution of BN signal for ferromagnetic steels (41 7140 and 41 2050) is controversial. Fig. 9 is a graphical illustration of the high as well as low BN signal found during the measurement for conventional steel 12 050. One might expect progressive and gradual change of BN signal as well as the effective value along with the developed VB. However, Fig. 10 shows that BN signal fluctuates in the range of employed *VB*. BN emission on ferromagnetic bodies after turning is driven 2 basic aspects. First one is associated with surface texture, preferential orientation of the matrix after turning (see also Fig. 12a and Fig. 12b) with contribute to higher BN emission due to preferential alignment of BW in tangential direction. On the other hand, increasing *VB* is connected with increasing mechanical and thermal load of machined surface. Such process initiates increasing dislocation density, compressive stresses, and alterations of carbides (their shape and size). All of these aspects tend to decrease BN [3].

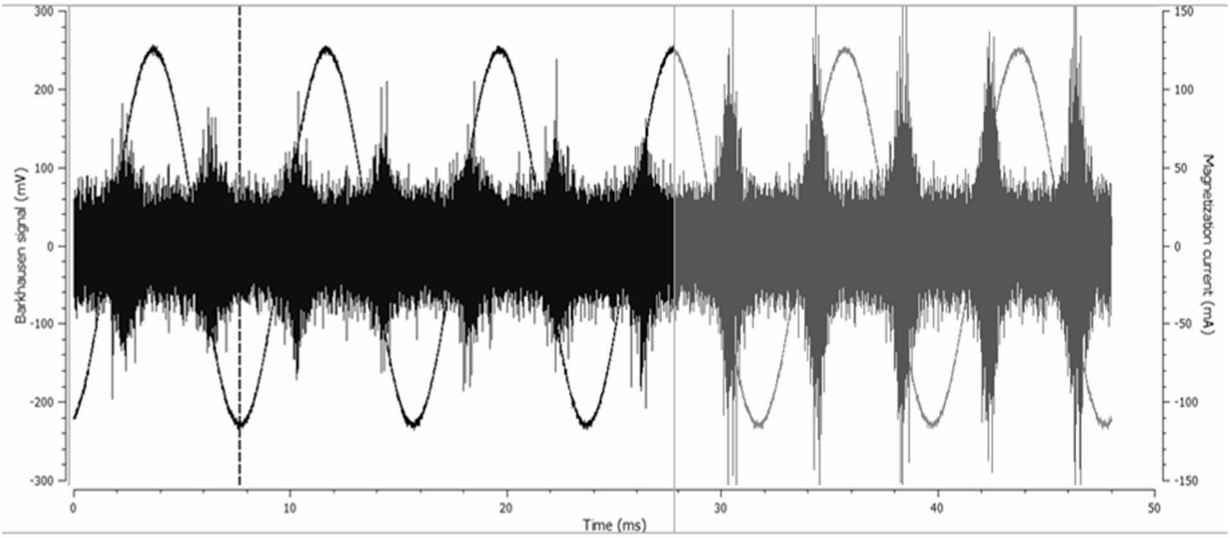


Fig. 8 *Raw BN signals for 41 7240, VB = 0.2 mm – black, VB = 0.9 mm – red*

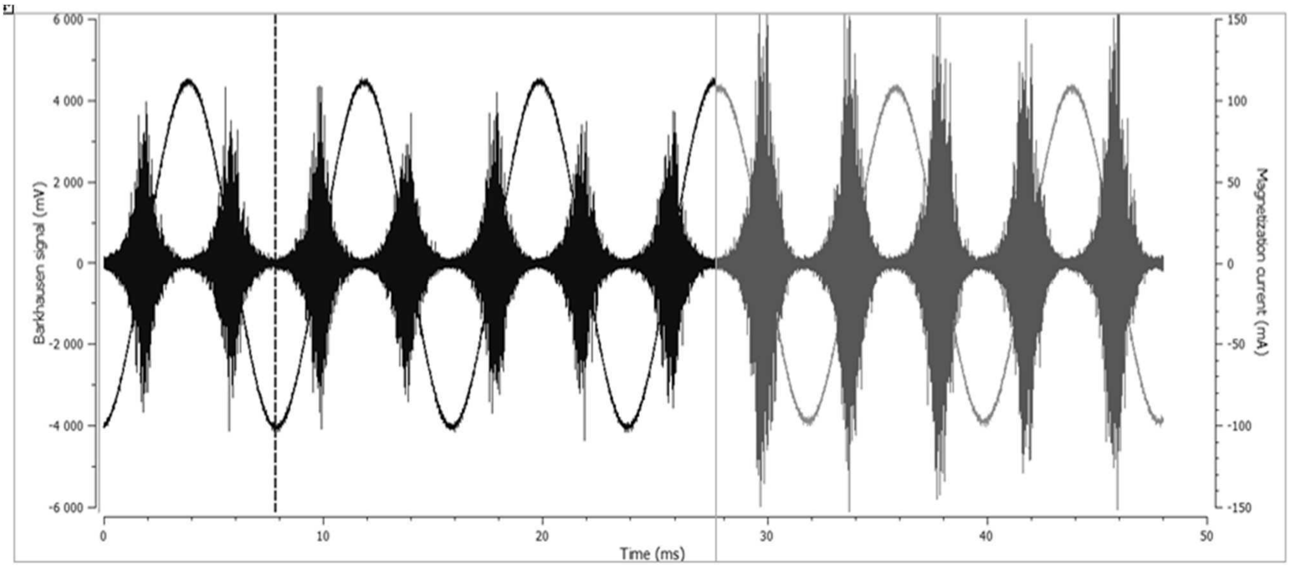


Fig. 9 *Raw BN signals for 41 2050, VB = 0.2 mm – black, VB = 0.5 mm – red*

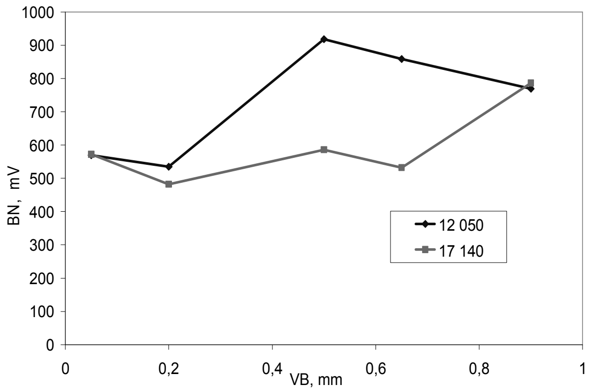


Fig. 10 *influence of VB on BN for ferromagnetic steels*

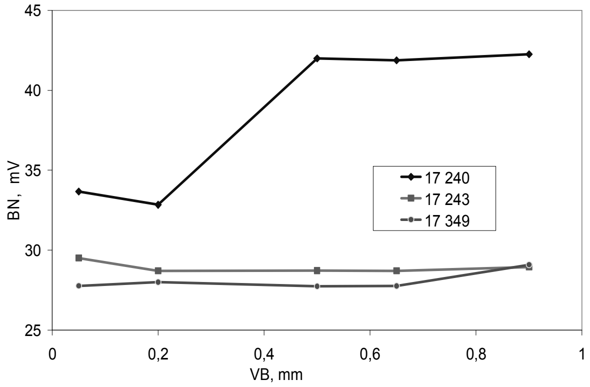


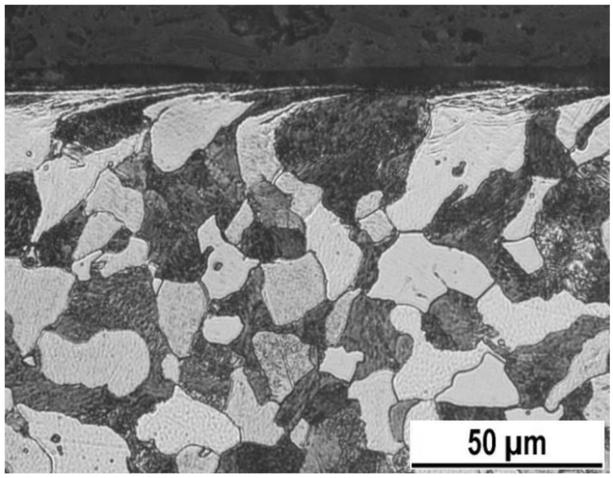
Fig. 11 *Influence of VB on BN for non ferromagnetic steels*

Non monotonous evolution of BN along with developed VB (as that shown in Fig. 10) is driven synergistic effect of the both above mentioned effects. Increase of decrease of BN with VB is driven predomination of preferential orientation or increasing density of crystalline defects hindering BWs motion (also compressive stresses).

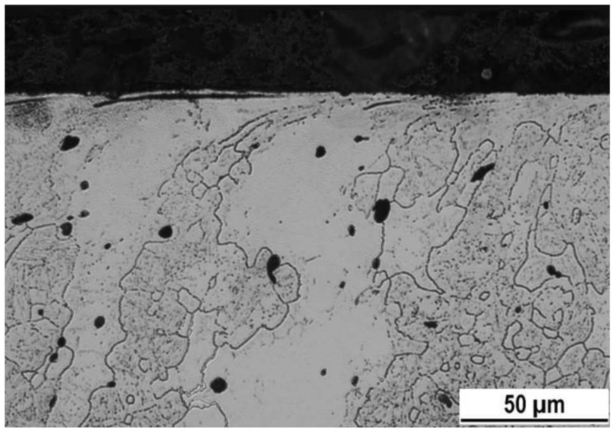
Metallographic observation confirms BN measurement findings especially considering turning austenite steels. Fig. 12d,e shows that machined surface does not exhibit any remarkable structure transformations for austenite steels 41 7243 and 41 7349. On the other hand, remarkable localized spots of ferrite can be found on the surface after turning steel 41 7240 as Fig. 12c illustrates. Localized character of ferrite spot on the machined surface is associated with increased cutting forces during turning along with more developed VB and corresponding higher intensity of vibration due to limited toughness of the machining system. Fig. 12c,d,e also shows that carbides in the matrix plays significant role. Carbides are sites hindering dislocation motion as well as protect the matrix against structure transformations [4]. Fig. 12c shows reduced density of carbides with in turn mean reduced resistance against austenite – ferrite transformation. On the other hand, especially microstructure of steel 41 7243 contains a great deal of carbides regularly distributed in the matrix. Being so, microstructure of this steel retains austenite despite quite intensive mechanical and thermal load during turning. Results of microstructure analysis of austenite steels fit very well with BN measurements.

4 Conclusions

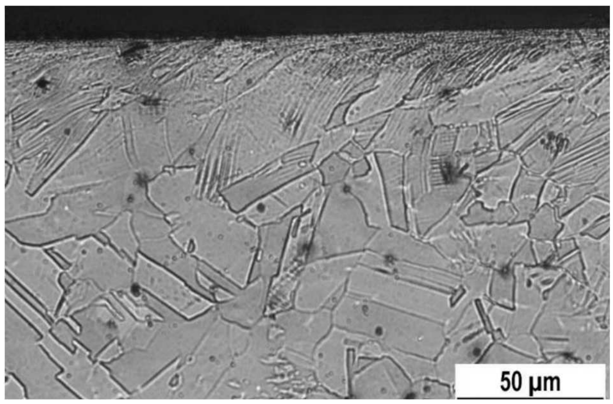
This study confirms that application of BN technique for machining operations of austenite stainless steels would be beneficial especially when structure transformations are expected. BN technique is capable to discover quite small and localized volumes of ferrite in the machined surface and match the information from conventional destructive tests. Furthermore, results of experiments considering machinability of variable stainless steels match with the industrial experience in the real production on components made of the investigated steels.



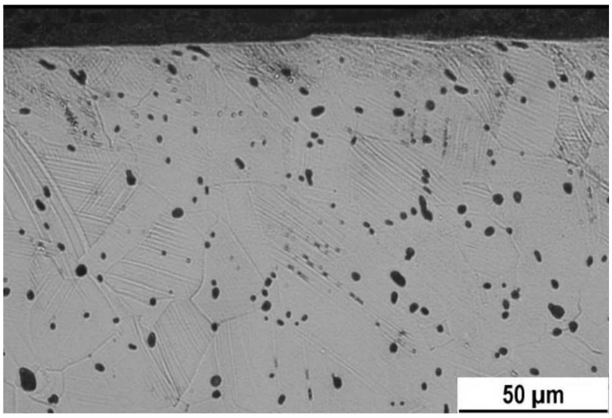
a) 41 2050



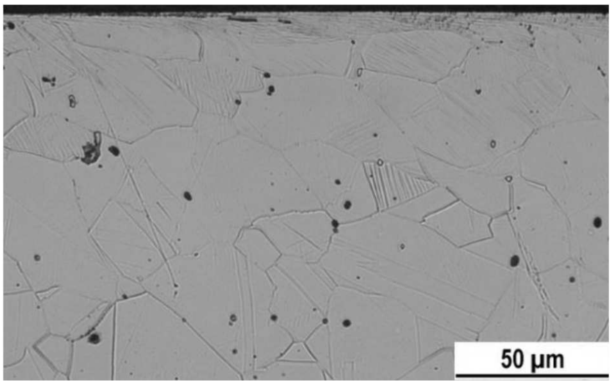
b) 41 7140



c) 41 7240



d) 41 7243



e) 41 7349

Fig. 12 *Microstructure of surfaces after turning, VB = 0.5 mm*

Acknowledgement

This study was supported by VEGA project n. 1/0121/17, KEGA project n. 008ŽU-4/2018 and APVV project "Danube strategy 2016-0013".

References

[1] HASHIMOTO, F., GUO, Y.B., WAREN, A.W. (2006). Surface Intergiry Difference between Hard Turned and Ground Surafces and its Impact on Fatique Life, *CIRP Annals*, Vol. 55/1, pp. 81 – 84.

[2] NESLUŠAN, M., TUREK, S., BRYCHTA, J., ČEP, R. (2007). Experimentálne metódy v trieskovom obrábaní. Edis Žilina.

[3] ČÍŽEK, J., NESLUŠAN, M., ČILLIKOVÁ, M., MIČIETOVÁ, A., MELIKHOVA, O. (2014). Modification of steel surfaces induced by turning: non-destructive characterization using Barkhausen noise and positron annihilation, *J. Phys. D, Appl. Phys*., Vol. 47, pp.1-17.

[4] NESLUŠAN, M., ČÍŽEK, J. KOLAŘÍK, K., MINÁRIK, P., ČILLIKOVÁ, M., MELIKHOVA, O. (2017). Monitoring of grinding burn via Barkhausen noise emission in case-hardened steel in large-bearing production, *J. Mater. Proc. Technol*., Vol. 240, pp.104-117.

[5] NESLUŠAN, M. et. all (2016). Barkhausen noise emission in case-hardened bearing steel, *Manufacturing technology* Vol. 16, pp. 214-220.

[6] MIČÚCH, M., et all. (2014). Micro magnetic study of cutting conditions and grinding wheel wear influence on surface integrity, *Manuf. Technol*., Vol. 14, pp. 66-71.

[7] SCHORNÍK, V. et. all (2017). Influence of ground end mill surface quality on cutting tool life, *Manufacturing technology* Vol. 17, pp. 952-957.

10.21062/ujep/179.2018/a/1213-2489/MT/18/5/793