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SURFACE LAYER PROPERTIES OF THE WORKPIECE MATERIAL IN HIGH PERFORMANCE GRINDING

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This paper focuses on the development of high temperatures in the cutting zone during high performance grinding. In order to identify the influence of grinding temperature on surface integrity, temperatures were measured in the workpiece surface layer under different machining conditions. Beside this, under the same conditions, the surface layer properties of the workpiece material were determined through metallographic examination. Microstructure and microhardness of the workpiece surface layer, as well as the burned surfaces and microcracks phenomena were investigated. The conducted experimental investigations allow the surface layer properties of the workpiece material in high performance grinding to be defined.

Key words: high performance grinding, workpiece surface layer, temperature, surface integrity

Stanje površinskog sloja materijala obratka kod visokoučinskog brušenja. U članku se ukazuje na pojavu visokih temperatura u zoni rezanja pri visokoučinskom brušenju. Da bi se ustanovio utjecaj temperature brušenja na kvalitet obrađene površine, izmjerene su temperature u površinskom sloju materijala obratka pri različitim uvjetima obrade. Ujedno je pri istim uvjetima obrade određeno stanje površinskog sloja materijala obratka metalografskim ispitivanjima. Ispitane su mikrostruktura i mikrotvrdoća površinskog sloja obratka i pojava nagorjelih površina i mikropukotina. Izvedena eksperimentalna istraživanja definiraju stanje površinskog sloja materijala obratka kod visokoučinskog brušenja.

Ključne riječi: visokoučinsko brušenje, površinski sloj obratka, temperatura, kakvoća obrađene površine

INTRODUCTION

Grinding is considered one of the most important machining methods in metal cutting. Basic advantages of grinding are high precision and surface quality with the ability to machining of difficult-to-cut materials and complex surfaces. Beside conventional grinding, high performance grinding processes have been introduced recently [1,2]. These systems use higher cutting speeds and/or depths of cut in order to increase a relatively low productivity which has traditionally been considered the main drawback of conventional grinding.

On the other hand, the increase of cutting conditions considerably changes the grinding kinematics. In high performance grinding there is a longer wheel/workpiece contact which leads to a more intensive friction, i.e. development of thermal energy in the cutting zone [3,4]. The unwanted thermal load, primarily of the workpiece surface layer, represents the basic limitation for further development of high performance grinding.

For that reason, in high performance grinding a special attention is focused on the effects of the grinding temperature on the surface layer properties of the workpiece material [5,6]. If the grinding temperature is high enough to cause structural transformations of the workpiece material, the surface layer may suffer greater damage [7-9]. Therefore, in order to enable machining of parts free of thermal defects, it is necessary to investigate the effects of heat affected zone on the workpiece surface layer.

EXPERIMENTAL PROCEDURE

Workpiece material used in the experiment was high speed steel (HSS), DIN S 2-10-1-8. The microstructure of investigated steel was martensite with fine globular cementite (Figure 1). The chemical composition of the tested specimen was as follows: 1,08 % C; 0,22 % Si; 0,23 % Mn; 0,014 % P; 0,019 % S; 4,1 % Cr; 1,5 % W; 9 % Mo; 1,1 % V and 8 % Co. Measured hardness was 66±1 HRc. Dimensions of used samples were 40×20×16 mm.

Experimental work was conducted on high performance surface grinding machine »Majevica« type CF 412 CNC with 50 kW instaled power. Porous aluminium oxide wheel »Norton«, type 32 A54 FV BEP, size 400×80×127 mm, was used in the testing. Water-based coolant (emulsion 6 %) was used during the grinding test with a flow rate of 175 l·min^{-1}.

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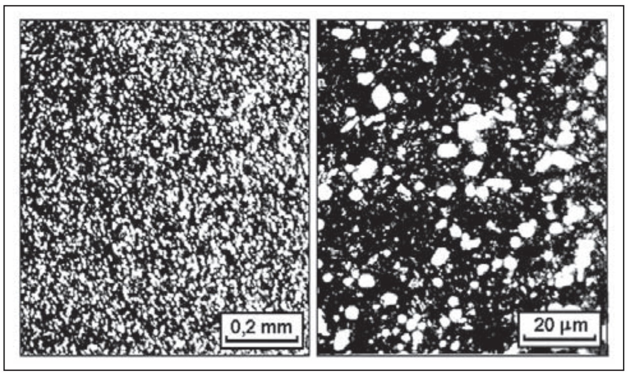

Figure 1 Microstructure of high speed steel, DIN S 2-10-1-8

The machining conditions included variable depths of cut and workpiece speed for a constant specific material removal rate $Q' = 2,5$ mm^3·(mm·s)$^{-1}$. The range of the depth of cut was $a = 0,05$ to 1 mm, while the workpiece speed was chosen from the intervale $v_w = 2,5$ to 50 mm·s^{-1}. The wheel speed was held constant $v_c = 30$ m·s^{-1}.

The temperature was measured in the workpiece surface layer using a thermocouples (type K, ø0,2 mm) built into the workpiece at a specified clearance from the wheel/workpiece interface area [10]. The real conditions of machining are in practice not disturbed by building in the miniature thermocouples, which enables high accuracy in measuring contact temperature. Hot junction of the thermocouple was positioned at $z = 1$ to 4 mm distance from the machined surface of the workpiece. Measuring, analysis and control of the temperature during the grinding process was performed with the help of a computerized acquisition system [10,11].

Surface integrity of grinding was assessed by research of the surface layer properties. Metallographic examinations of microstructure, microhardness, burned surface and microcrack were performed on an optical microscope with 200× magnification "Aristomet" of Leit, Germany. Examinations were performed on previously prepared samples in a transversal section where the thermocouple was built-in, immediately beside the measured contact temperature of grinding.

RESULTS AND ANALYSIS

In order to identify the influence of grinding temperature on the surface layer properties, the temperature fields in the workpiece surface layer were determined under different machining conditions. Temperatures were measured at various distances from the contact surface of the wheel/workpiece. The characteristic diagram - showing the change of contact temperature with time in the cutting zone ($z = 0$ mm), for conventional and high performance grinding during constant specific material removal rate - is shown in Figure 2.

The results of temperature measurements allow analysis of the heat affected zone on the workpiece surface layer through the power of heat source and its duration time. As can be seen from the diagram, high performance grinding significantly increases the intensity of heat source parameters.

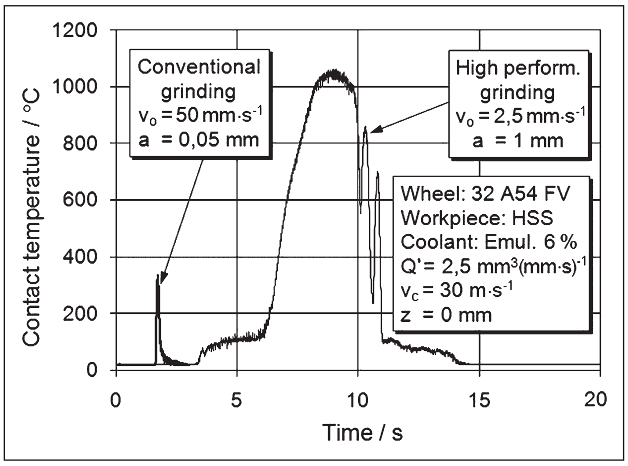

Figure 2 Distribution of contact temperature in conventional and high performance grinding

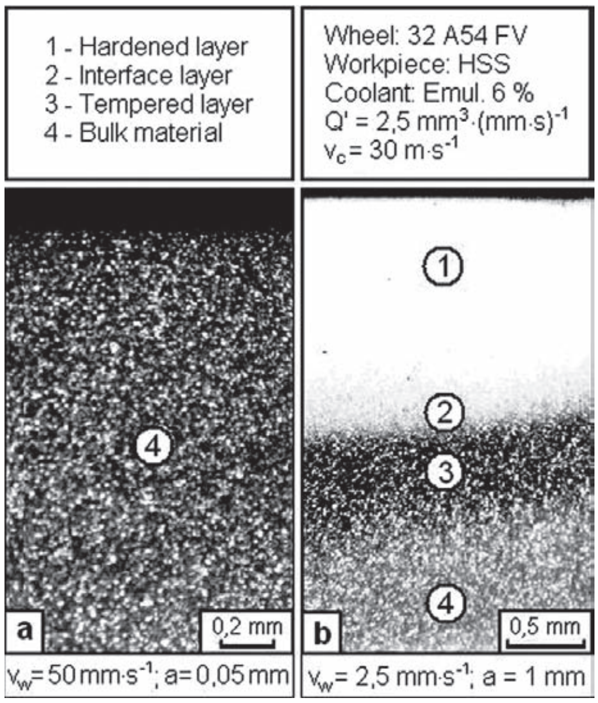

Figure 3 Typical metallographic photos of the recast layer for high speed steel, a) conventional grinding, b) high performance grinding

Therefore, high grinding temperatures may generate a heat affected zone in the workpiece surface layer. Figure 3 shows metallographic photos of surface layer of the investigated high speed steel. Metallographic examinations showed presence of recast layer in high performance grinding. The formed recast layer manifests through uniform thickness of microstructure transformations compared to the bulk material.

The analysis of metallographic photos revealed three characteristic layers: hardened layer, interface layer and tempered layer (Figure 4). The hardened layer consists of martensite, residual austenite and cementite. The interface layer consists of martensitic-austenitic grid and cementite, where the ratio of austenite diminishes with the distance from the tempered layer. The microstructure of the tempered layer is tempered martensite and cementite, which gradually phase into basic microstructure consisting of martensite with fine globular cementite.

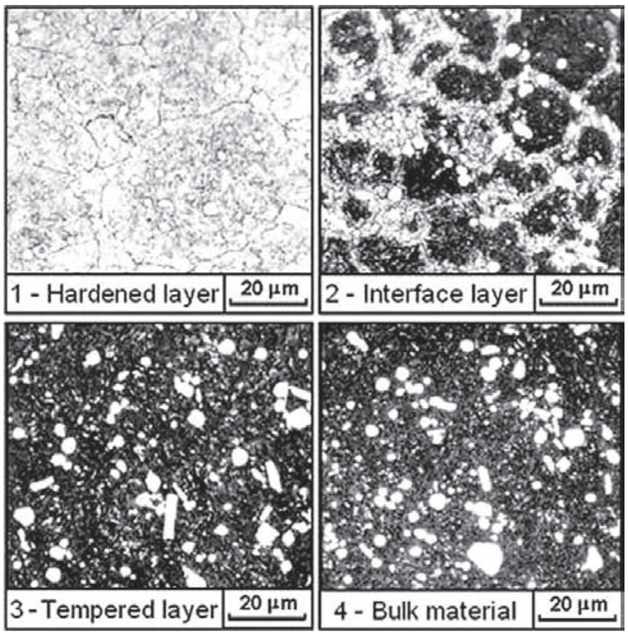

Figure 4 Microstructures of the surface layer for high speed steel after high performance grinding

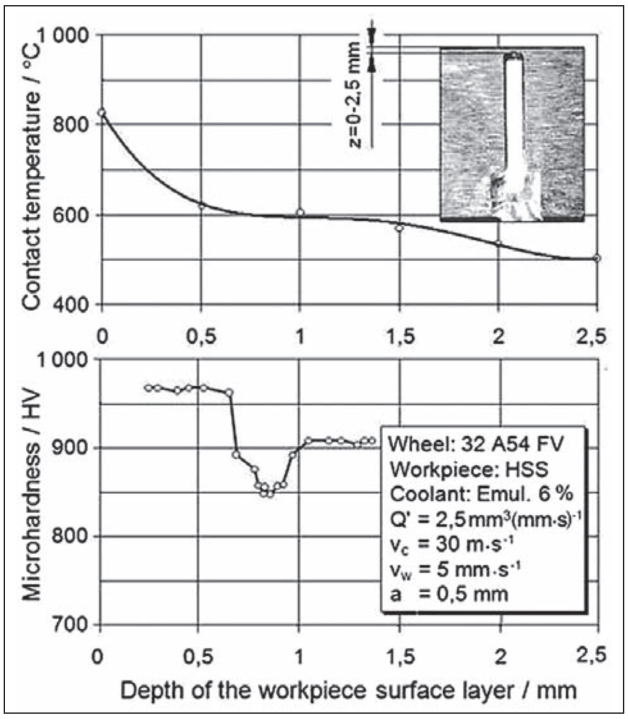

Figure 5 Changes of temperature and microhardness with the depth of the workpiece surface layer in high performance grinding

Table 1 shows recast layer thicknesses of the tested specimens. The examinations showed that recast layer thickness is directly proportional to the heat affected zone. The recast layer appeared in case when the contact temperature was higher than the temperature of previous tempering, which is 550 °C for the steel that was used in testing. At the same time, if the contact temperature does not exceed the austenite-to-ferrite phase transformation temperature, which is 723 °C for steel containing more than 0,8 % C, only the tempered layer can be registered. In the opposite case, if the temperature goes beyond, all three characteristic layers are registered.

Figure 5 shows the diagram of change of temperature and microhardness with depth of the workpiece surface layer in high performance grinding.

The distribution of grinding temperature within the depth of the workpiece surface layer was determined with the maximum temperature measured during approaching of the grinding wheel to the hot junction of the thermocouple. Maximum value of contact temperature and time of impact in workpiece surface layer are most important for surface integrity.

Compared to the bulk material (microhardness was 908,9 HV), the hardened layer has higher (968,6 HV), while the tempered layer had a lower microhardness (847,7 HV). Higher microhardness of the hardened layer was the result of the austenitic-martensitic phase transition, while the lower microhardness of the tempered layer occured around the highly tempered grains in the martensitic-austenitic grid.

Further identification of surface layer properties included the cracks, microcracks and burned surfaces (Figure 6). Cracks and microcracks appeared only at the groove of the thermocouple. On the other hand, burned surfaces were noticeable in all samples where the contact temperature was above the temperature of the previous tempering. At the same time, high contact temperatures of high performance grinding initiated more explicit appearance of burned surfaces.

CONCLUSIONS

Based on the analysis of experimental results, the following conclusions can be drawn:

- High performance grinding process leads to a significant increase of contact temperature in the cutting zone;
- Excessive temperature generates a heat affected zone in the surface layer of the workpiece material;

Table 1 **The recast layer thickness of high speed steel in conventional and high performance grinding**

Machining conditions			Contact temperature T / °C	Recast layer thickness			
Depth of cut a / mm	Work speed v_w / mm · s^{-1}	Wheel speed v_c / m · s^{-1}		Hardened Layer / mm	Interface layer / mm	Tempered Layer / mm	Recast Layer / mm
0,05	50	30	334	Without a recast layer			
0,1	25		389	Without a recast layer			
0,25	10		586	-	-	0,2	0,2
0,5	5		827	0,7	0,15	0,3	1,15
1	2,5		1062	1,2	0,6	0,8	2,6

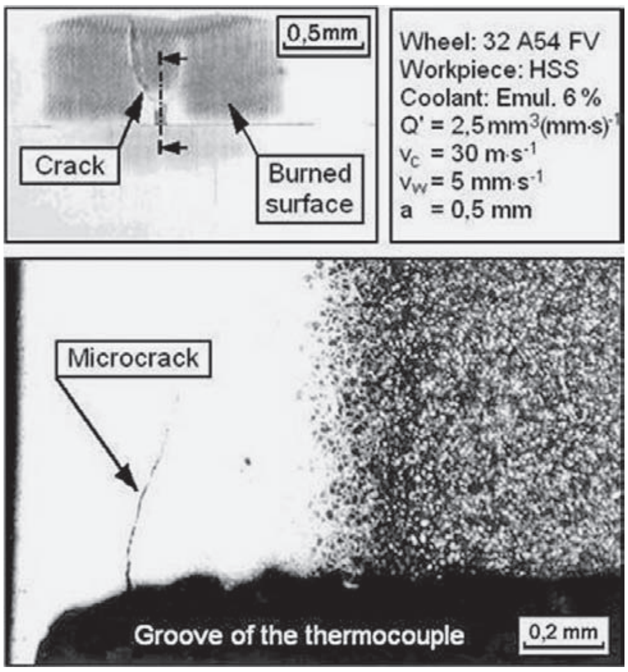

Figure 6 Characteristic photos of crack, microcrack and burned surface after high performance grinding

- Metallographic change was detected in all cases when the contact temperature was higher than the temperature of previous tempering;
- Recast layer thickness is in direct proportion with the height of grinding temperature;
- Compared to the microhardness of the bulk material, microhardness of the hardened layer was higher, while that of the tempered layer was lower;
- Cracks and microcracks were noticed at the groove of the thermocouple;
- Burned surfaces appeared in cases when the grinding temperature exceeded the temperature of previous tempering.

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Note: The responsible translator for the English language is Ognjan Lužanin, University of Novi Sad, Serbia