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INVESTIGATION OF MACROSCOPIC RESIDUAL STRESS DISTRIBUTION AFTER PROGRESSIVE MACHINING OF TOOL STEELS

VÝZKUM DISRIBUCE MAKROSKOPICKÝCH ZBYTKOVÝCH NAPĚTÍ PO PROGRESIVNÍM OBRÁBĚNÍ NÁSTROJOVÝCH OCELÍ

Abstract

HSC (High Speed Cutting) and EDM (Electro Discharge Machining) belong to the progressive and harsh machining operations. They differ markedly in the manner of material removal and, consequently, in the process of a final surface formation. While HSC represents the so called chip machining, EDM embodies a utilization of controlled thermal material reduction. With respect to the usage of these technologies, tool steels *K110* and *W300* were chosen for the experiments. Samples made from both the materials were primarily subjected to either HSC or EDM and residual stresses were investigated by means of X-ray diffraction, Barkhausen noise, hole-drilling, and layer removal methods.

Abstrakt

HSC (obrábění vysokými rychlostmi) a EDM (elektroerozivní obrábění), které patří k progresivním a extrémním způsobům obrábění, se liší zejména z hlediska základního principu úběru materiálu a tvorby finálního povrchu. Zatímco HSC je zástupcem progresivního třískového obrábění, technologie EDM reprezentuje specifickou oblast využití řízeného tepelného úběru materiálu. S ohledem na praktické použití těchto technologií byly pro experimentální studium vybrány nástrojové oceli *K110* a *W300*. Vzorky vyrobené z těchto materiálu byly obrobeny v různých režimech HSC a EDM a následně byla provedena tenzometrická analýza zbytkových napětí pomocí následujících experimentálních metod: rtg difrakce, Barkhausenův šum (magnetoelastická metoda), odvrtávací metoda a metoda postupného elektrolytického rozpouštění.

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1 INTRODUCTION

The goal of this research was an investigation of HSC [1] and EDM [2] technologies. They differ significantly in the fundamentals of material removal and, consequently, in the process of the final surface formation. HSC was chosen as a typical operation representing chip machining, when the energetic balance is determined above all by the intensity of transformation of mechanical work into heat originating in the cutting zone [3]. EDM epitomizes a specific utilization of a controlled thermal material reduction with the energetic balance given directly by the amount of energy present in the machining area during revolving discharges and successive melting [4].

2 INVESTIGATED SPECIMENS

Samples under investigation were made from two high-quality tool steels; cold work ledeburitic *K110* tool steel (X153CrMoV12) [5] and hot work ferritic-perlitic *W300* tool steel (X38CrMoV5-1) [6]. Both hardened and unhardened samples were at disposal. Material *K110* was hardened and twice tempered onto secondary hardness of 58 – 60 HRC, *W300* was hardened and twice tempered onto hardness of 53 – 54 HRC.

Before treating of HSC milling and EDM, the plates of dimensions 30×20×8 mm^3 were subjected to face grinding in order to guarantee homogeneous and uniform initial surface quality. The thickness of removed layer was 0.02 mm, the last grinding operation was sparking-out. Eventhough the grinding itself induces new residual stresses to the surface layers. It has been shown [1] that homogeneous surface before machining is highly desirable.

2.1 HSC milling

Face milling was carried out on a *DMC 104V LINEAR* milling machine by end milling cutter which had five embedded round tool tips. Since the hardness of material in basic and hardened state differed significantly, two types of tool tips had to be used (*02 10 835 PVTi* for hardened and *02 10 842 P40* for unhardened). The remaining machining conditions were as follows: tool diameter – 32 mm, number of tool teeth - 5, cutting operation down-milling, cutting speed: 150-1250 $m.min^{-1}$, feed per tooth - 0.05 mm, axial depth of cut - 0.2 mm, radial depth of cut – 22 mm. The cutting was done in natural environment (i. e., no coolant was used). The above mentioned range of cutting speed corresponds to the volume output Q_V = 39 – 330 $mm^3.s^{-1}$ and to the specific work 5 –10 J. mm^3.

2.2 EDM

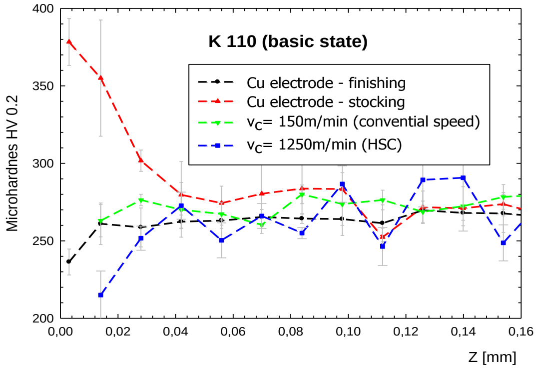
A *WALTER Exeron S 204* device with a pulse generator with power of 9 kW and current of 180 A was used. The polarity was indirect, i. e., tool (-) and workpiece (+). Two modes of machining were applied: (i) *stocking* characterized by higher material reduction, high energy of discharges and lower values of discharge frequency with estimated surface roughness Ra not exceeding 6,3 μm; (ii) *finishing* with lower energy and higher frequency of discharges with desired surface quality up to 1,6 μm. The used device enabled the following operational conditions: U_Z = 100 – 260 V, I_e = 10 – 160 A, f = 10 – 100 kHz, Q_V up to 20 $mm^3.s^{-1}$, corresponding to the specific work ranging from 100 to 1000 J. mm^3.

3 EXPERIMENTAL METHODS

Surface and near-surface states of residual stress (RS) were analysed by means of following experimental techniques: X-ray diffraction (XRD) "*one tilt*" [7] and "$sin^2\psi$" method [8], Barkhausen noise (BN) [9], layer removal method (LRM) [10] and hole-drilling method (HD) [11]. These methods were complemented by micrographs and by microhardness measurements.

4 RESULTS

Limited extent of this article allows us to present only a representative selection of the obtained results (Figs. 1 - 4).



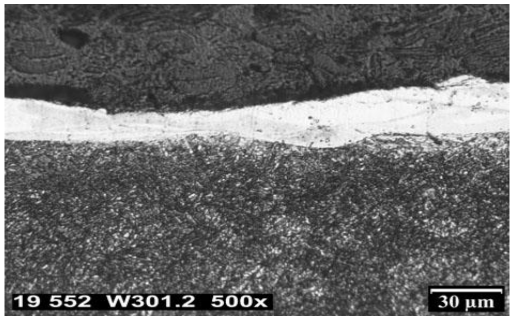
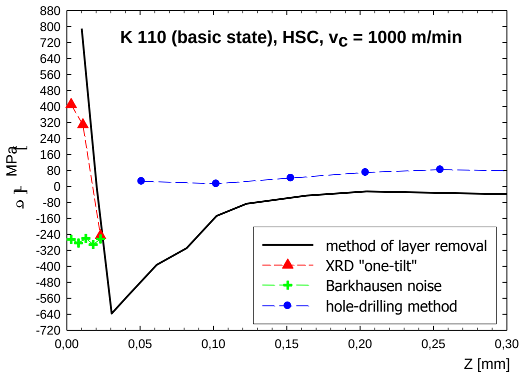


Fig. 1. & 2. Distribution of microhardness in surface layers of unhardened *K110* (left) and microstructure of hardened steel *W300* after EDM (stocking, Cu electrode).



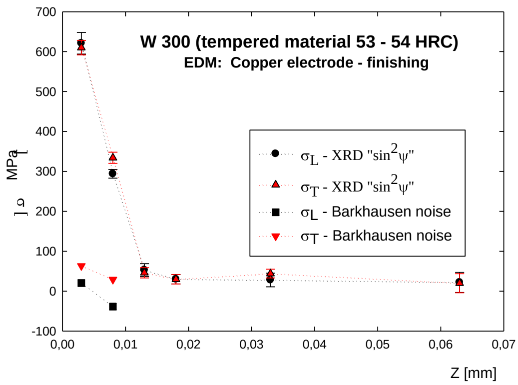


Fig. 3. & 4. Macroscopic RS σ_L, determined by XRD ("*one tilt method*"), Barkhausen noise and hole-drilling method (left), macroscopic RS σ_L, σ_T determined by XRD ("*sin*$^2\psi$").

5 CONCLUSIONS

It should be emphasized that the methods applied for residual stress determination are based on different physical principles which might lead, and actually did, to differences in obtained results.

XRD analysis identified equi-biaxial state of RS (i. e., $\sigma_L \approx \sigma_T$) for all the analysed surfaces and near-surface layers of samples which were subjected to EDM. The regime *EDM finishing* resulted in tensile RS, whereas *EDM stocking* produced compressive RS.

Samples machined by HSC exhibit differences exceeding measurement inaccuracy of the values σ_L and σ_T. With regard to the technological usage, the state of RS in the direction of advance (σ_L) of cutting tool will be discussed in the following.

No pronounced difference with respect to the cutting speed was found in RS distribution obtained by LRM. The initial presumption of decreasing RS with increasing cutting speed is, therefore, not fulfilled which might be caused by the finalisation character of side milling.

The surface RS, according to both LRM and XRD, are tensile in unhardened and compressive in hardened cold work *K110* steel. The results of BN indicate a compressive RS without any change in depth. This might be caused by sensitivity of magnetic BN method not only to the strains, but to the microstructure of material as well.

The results of LRM and XRD are contradictory for both unhardened and hardened state of hot work W300 steel. For hardened samples XRD and BN give similar values of residual stress not corresponding with LRM, which found compressive surface RS in all samples.

The investigated steels have different structure and consequently different temperature range for their application; *K110* (ledeburitic structure with hard carbides, high content of carbon – 2 %) is used for cold work since *W300* (ferritic-perlitic structure with carbon content of 0.4 % and soft matrix) for hot work. *K110* is harder and hence a more intensive heat flux is present during milling. As this steel is intended for cold work (at less than 300 °C), the tensile stresses on the surface arise. Distribution of RS is given by the balance of mechanical and thermal influences. On the contrary, *W300* is softer and hence thermal effects are subdued by plastic deformation. Moreover, this steel is used for tools working in high temperature environment (above 300 °C); therefore compressive stresses on the finish milled surface should be obtained.

Experimental measurements by HD method proved that even tool steels can be drilled by a conveniently chosen tool. Diamond tool cutter can be used for both hardened and unhardened *K110* steel. *W300* steel requires tool cutter *SINTCTT* and diamond cutter is not at all suitable.

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