ANALYSIS OF HEATED AFFECTED SAMPLE SURFACE AFTER WEDM PROCESS

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ANALÝZA TEPELNÉHO OVPLYVNENIA POVRCHU VZORKY PO PROCESE WEDM

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Abstrakt

Cieľom príspeku je popísať reálny priebeh hĺbky tepelne ovplyvnenej zóny v podpovrchových vrstvách vzoriek, ktoré boli vyhotovené technológiou elektroerozívneho rezania drôtovou mosadznou elektródou. Potrebne je však hneď v úvode poznamenať, že toto ovplyvnenie je z hľadiska životnosti objektov vyrobených touto progresívnou technológiou nežiaducim javom. Vysoká hodnota hĺbky tepelne ovplyvnenej zóny, jej charakteristika a nerovnorodý priebeh v celom priereze, výraznou mierou prispieva k zníženiu kvality a skráteniu doby životnosti tak strojových súčastí, ako aj rezných nástrojov. Vzorky boli vyhotovené na elektroerozívnym strojom AGIECUT z nástrojovej ocele s pevnosťou 950 MPa. Ako rezný nástroj bola použitá drôtová mosadzná elektróda s priemerom 0,25mm. Pri stanovení vhodnej metodiky merania hĺbky tepelne ovplyvnenej zóny bolo nevyhnutné vychádzať zo špecifík danej technológie, kde k ovplyvneniu a následnej zmene mikrotvrdosti dochádza bezprostredne po bodovom pôsobení vysokej teploty elektrického výbojového kanála, ktorý vzniká medzi drôtovou elektródou ako rezným nástrojom a kovovým materiálom čiže obrobkom za intenzívneho ochladzovania v ponorenom dielektriku. Z hľadiska tohto aspektu vykazuje ovplyvnenie iné hodnoty v pozdĺžnom a iné priečnom reze, ktorý je odvodený od smeru pohybu drôtovej elektródy vzhľadom k obrobku. Priebeh je zároveň do značnej miery ovplyvnený vzájomnou kombináciou technologických parametrov, ktoré však nevyhnutne musia rešpektovať elektroerozívny rezný proces, ako aj elektrochemické vlastnosti deleného materiálu.

Abstract

The aim of this paper is to describe real course of the depth of heat affected zone in sub-surface layers of the samples made by technology of wire electrical discharge machining with brass electrode. It is vital to remark in the beginning that the heat impact is an undesirable phenomenon from the standpoint of operating life of parts produced by this progressive technology. Considerable depth of heat affected zone, its characteristic, and its uneven course along cross-section, noticeably contribute to the decrease of quality and longevity of machine parts, as well as cutting tools. The samples were produced on electroerosion machine AGIECUT from tool steel of 950 MPa strength. Applied cutting tool was wire brass electrode of 0.25 mm diameter. To determine suitable HAZ depth measuring method it was necessary to take into account properties of the given technology where impact and consecutive micro-hardness change occurs instantly after high temperature spot effect of electric discharge channel which arises between wire electrode (cutting tool) and material (workpiece) during intensive cooling in dielectric medium. Considering this aspect, the influence shows different values in longitudinal and lateral cross-sections (as of wire electrode movement relatively to the workpiece). The course of the values is in the same time greatly affected by combination of technological parameters that inevitably must observe electroerosion cutting process itself, as well as electro-chemical properties of the material.

Keywords: Parameters of Technological Process, Heat Affected Zone (*HAZ*), Quality of Surface, Wire Electrical Discharge Machining (*WEDM*)

1. Introduction

The task of the research is to contribute to understanding of the processes that occurs in WEDM, the aim is formulation of relation in coupling with processes. Electroerosion process belongs to thermal processes where certain structural changes under cut material surface can be expected. An essential parameter which defines surface quality of the workpiece in WEDM is depth and course of heat affected zone. It must be pointed out that heat influence on workpiece surface during electroerosion cutting is in most cases undesirable. Exceptionally liable to this effect are shear tools where undesirable HAZ influence can decrease operating life by 20%. Understanding and consecutive control of the process would make it possible to create surface layers with pre-defined quality.

2. Sample Surface After Eroded

The surface after electroerosion is matte, nevertheless it renders the same roughness as glossy surfaces. High quality of surface is favourably influenced by conductibility of the material and its melting point temperature. Concerning high hardness and strength of applied material, no negative changes of surface quality (such as increased HAZ depth) were observed. Discharge plasma channel with high density and high temperature caused structural change of basic material surface, whilst integrity of the material was retained. Melted layer contains fractions of hydrogen, oxygen, and small melted-off particles from brass electrode (Fig. 1).

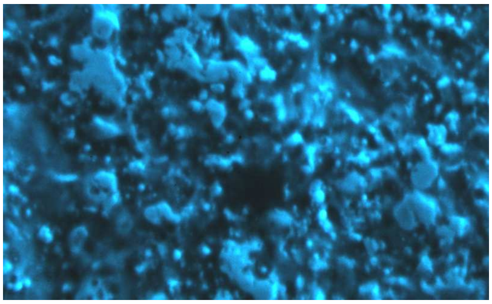


Fig.1 Sample surface after electroerosion cutting process (500 x magnifications)

Figure 1 responds to the first cut condition. The presence of generating carbides increases hardness and fragility of surface layer. Under the melting surface layer there is a heat affected zone in which structural changes take place [4].

Depth of *HAZ* depends on initial structure of cut material, on character of phase changes that took place during the process, and on combination of cutting parameters. Overall depth of impact on yet unmachined surface ranges from 10 to 30 μm. Next figure it shows experimental frame of heat affect zone recorded with electronic scope.

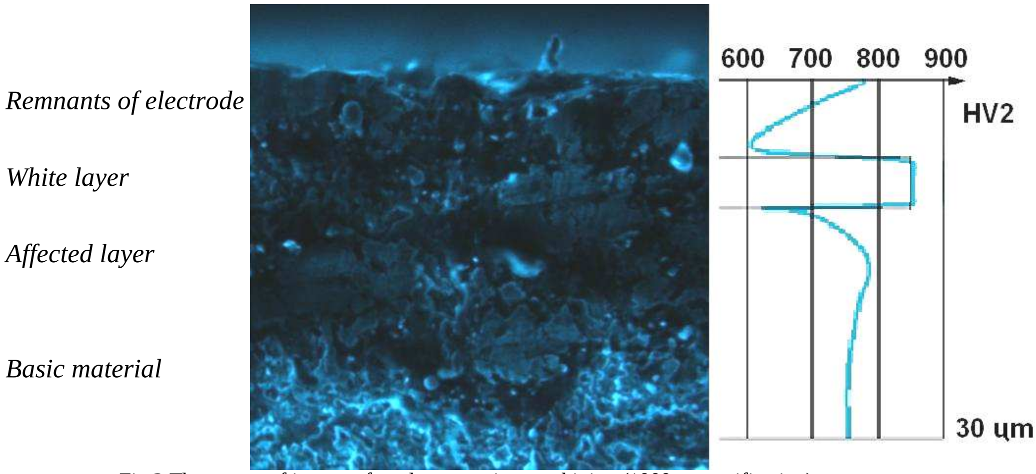


Fig.2 The course of impact after electroerosion machining (1000x magnification)

Figure 2 shows diagram of micro-hardness course in surface layers of steel hardened to app. 850 HV2. It was proved that hardness directly under surface sharply drops to value around 620 - 640 HV2, however, in *white layer* it substantially grows to 800 - 830 HV2. From this value hardness falls again to 620 - 640 HV2. In transition layer hardness rises once again to reach hardness value of basic material [4].

3. Reform the Samples before the Experiment

Before electroerosion cutting the metal block from steel EN ISO 9679 X210 CR12 (STN 19 436) was oil-hardened to approx. 64 HRC from 950 °C and then tempered at 220 °C to approx. 61 HRC, in order to eliminate internal stress which emerged in hardening process. It was necessary to deprive oxidation layer (rust) from eroded samples´ surface. This was done chemicaly, the samples were immersed in solution based on concentrated phosphoric acid (H_3PO_4 of 90% concentration) and Armohib 25 stain solution at constant temperature 20 °C. To ensure accurate measurements it was inevitable to remove brass deposit from the surface of the samples which originated from wire electrode. The deposit was removed by spraying solution of water and concentrated ammonia (0.9 $g.cm^{-3}$) with ratio (water : ammonia = 9 : 1) plus additives – ammonium persulphate (0.2 g to 10 cm^3 of solution), and sodium phosphate (0.1 g to 10 cm^3 of solution). Remnants of etched-out layer were then removed from the surface by blasting with glass balls of 50 μm diameter and spot load of blasting balls for approximately 3 s on cm^2 of sample surface. Blasting nozzle was in 40 mm distance from sample surface at 30° angle.

4. Characteristic of Main Technological Parameters

Main technological parameters that considerably influence cut quality (from the view of *HAZ* depth) are working cutting current, duration of electric discharge and pause for renewal of the discharge channel (called OFF-time pulse). An influence of these parameters on *HAZ* quality together with range of their adjustments applied in experiment are shown in tab. 1.

Table 1 Basic technological parameters influencing micro-hardness and their adjustment ranges applied in experiment

Technological parameter (TP)	Adjustment range of TP applied for experiment		Influence on HAZ
	thickness mat. 10 mm	thickness mat. 100 mm	
Working cutting current ″*I*″ [A]	0.3 ÷ 5.8	2.5 ÷ 8.25	With increasing current value surface roughness grows, cutting gap extends and depth of heat-affected zone grows.
ON time pulse ″*t*″ [μs]	1.5 ÷ 7	0.2 ÷ 8	With ″*t*″ increase roughness grows, cutting speed and *HAZ*.
OFF time pulse ″t_d″ [μs]	1 ÷ 4	0.1 ÷10 μs	With growing ″t_d″ shape inaccuracy appears and *HAZ* degrades.

5. Experimental Device and Measurement Methodology

Experimental device using for experiment:

- electroerosion cutter machine AGIECUT DEM200
- Vickers Hadrness Tester HPO 250
- Electron Microscope HRTEM JEOL JEM 3010

Considering small depth of *HAZ*, certain problem with micro-hardness measuring method arose. As the best method which respects specifics of this progressive technology appears to be the method of oblique section. In order to achieve accurate results, it was necessary to produce metallographic polished section at a very small angle because *HAZ* depth ranges from 10 to 30 μm.

Measurement was done on metallographic polished section at angle α, the stab distance from the surface was established by the formula [6]:

$$h = h_s \cdot \sin\alpha \qquad (1)$$

where: h_s - assumed *HAZ* depth
α - angle of metallographic section

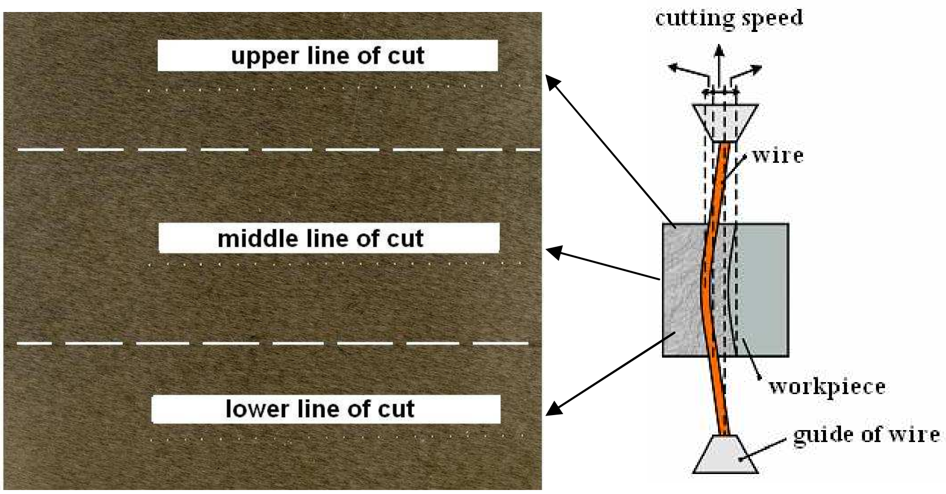


Fig.3 Experimental measurement of HAZ depth

In *HAZ* observation, stabs were done by steps from an edge of the section to material interior until micro-hardness value stabilized on its constant value equal to basic material hardness 750 HV2. In order to respect surface micro-profile, and micro-hardness course, the measuring stabs were done in three lines in identical distance from the real surface [5].

Because of high hardness value of basic material, it was not possible to apply Vickers micro-hardness test. At Vickers test applied loads range from 0.098 N to 0.98 N which is insufficient for the given basic material hardness. This method can be used for micro-hardness measurement up to 464 HV 0.1 that equals Rockwell hardness of approximately 45 HRC. Basic material was hardened to 61 HRC therefore low load Vickers hardness test according ISO 6507 was applied on the device HPO 250 Vickers Hardness Tester. Applied load at test was 19.61 N for hardness HV2.

6. Evaluation of Experimental Measurements

The best evaluation method in this experiment appears to be Minimum Square Method. It is a numerical method which, in general, approximates *n*-tuple of measured values $[x_1, x_2, ..., x_m, y]$ by function of *m* variables in form

$$y = f(x_1, \ldots, x_m) \tag{2}$$

According to the type of function course an exponential function with natural number base can be predicted as a suitable function type which we will use to interlace values:

$$y = a_{00} \,.\, a_{10}^{x_1} \,.\, a_{01}^{x_2} \,.\, a_{11}^{x_1 x_2} \tag{3}$$

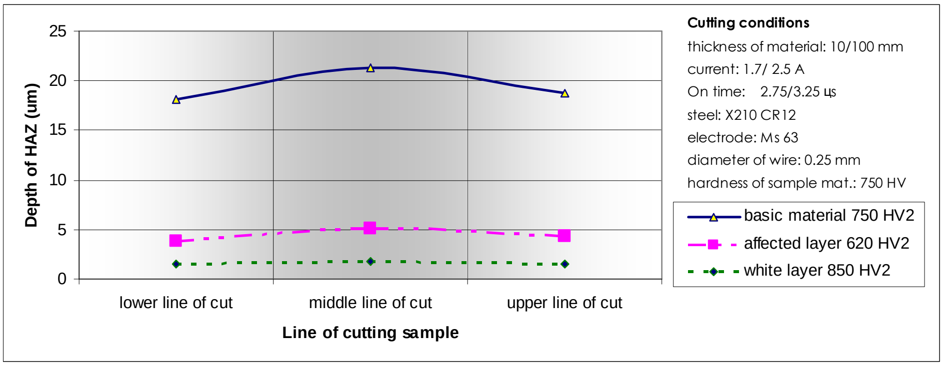
As it was mentioned in previous, the task is to approximate measured values of *HAZ* depth h_{HAZ}. On the basis of measured values we assume that the best approximation will be function in form (3), which is function with seven variables, it can be written in the form:

$$h_{HAZ} = a_{00} . a_{10}{}^{I} . a_{20}{}^{I^2} . a_{30}{}^{I^3} . a_{01}{}^{t} . a_{02}{}^{t^2} . a_{03}{}^{t^3} \tag{4}$$

that is, it approximates *n*-tuple of measured values $\left[I_i, t_i, h_{HAZ_i}\right]$ with functional relation

$$h_{HAZ} = f(I, t, \mathbf{A}) = f(I, t, a_{00}, \ldots, a_{rr}) \tag{5}$$

where unknown parameters a_{ij}, i, j = 0, …, r are calculated so that the area would best approximate measured functional values.



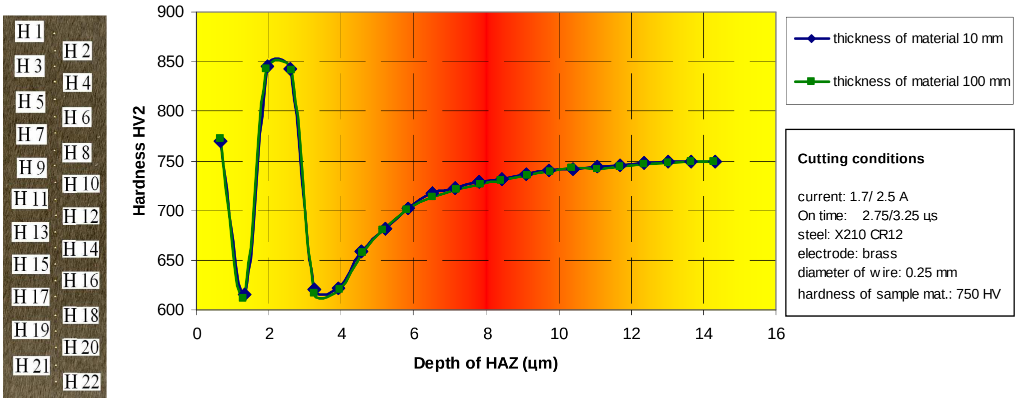
Diagr.1 Measured values of HAZ depth in the three lines

Then mathematical model of dependence of *HAZ* depth on working cutting current and pulse duration calculated with program OpenOffice ***EXCEL*** by logarithmic regression can be written in the form [3]:

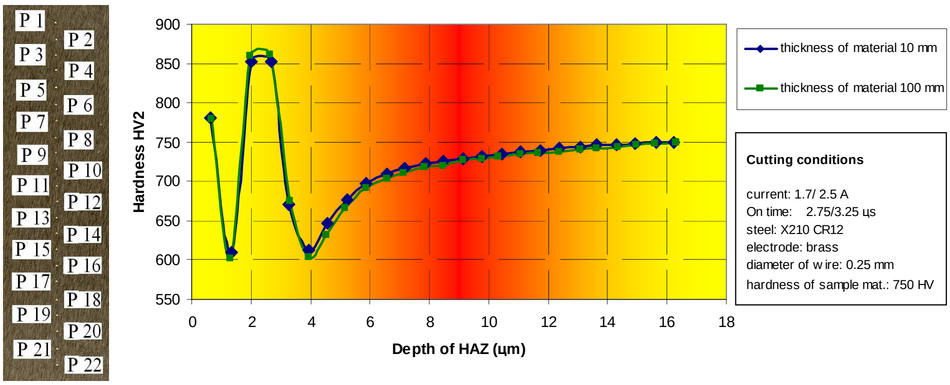
$$\boxed{h_{HAZ} = 11.7818\, 1.001^{I} \cdot 1.00012^{I^2} \cdot 0.9928^{I^3} \cdot 1.00021^{t} \cdot 0{,}0999^{t^2} . 1{,}00551^{t^3}\ [\mu m]} \qquad (6)$$

correlation index is R^2=0,9887

where h_{HAZ} – *HAZ* depth [μm]
I – working cutting current [A]
t – pulse duration [μs]



Diagr.2 Course of HAZ in surface layers (cut thickness 10 and 100 mm), in upper and lower line of the cut



Diagr. 3 Course of HAZ in surface layers (cut thickness 10 and 100 mm), in middle line of the cut

Experimental measurements prove that the thickness of cut material renders almost no influence on *HAZ* size. Size of impact in first (stock) cuts (*Ra* = 3,6 μm) ranges from 15 to 20 μm. The curves of hardness course in marginal lines show steeper characteristic comparing to middle line. In the middle area, decreased surface roughness approaches hardness value of basic material in greater depth.

7. Conclusive Evaluation of the Experiment

High values of working cutting current in unsuitable combination with pulse duration can yield considerable increase of *HAZ* size in electroerosion machining. However optimum relation of these parameters makes it possible to achieve acceptable *HAZ* values. In the same time it is vital to take into account economic efficiency of cutting process, it means that parameters´ adjustment ranges must – besides cutting process itself – follow efficiency of cutting without considerable loss of cutting performance.

The aim of the experiment was observation of the size and quality of heat affected zone (*HAZ*) at electroerosion cutting with brass wire electrode. Upper and lower edge of the cut rendered approximately the same depth and hardness of sub-surface layers. More marked difference was discovered in the middle part of the cut where measured values were in average higher by 20 HV2, and impact extended deeper comparing to the edges of the cut.

Recommendations for the practice are to adjust OFF time pulse to 20% higher value. This will cause a decrease of cutting power in the middle part of the cut. Decrease of idling impulses ratio will raise cooling time for basic metal core and thus will cause higher homogenity of heat affected zone in whole profile of the cut. The OFF-time-pulse duration increase exceeding 20% and related further reduction of idling impulses ratio can cause adverse effect, which is characterized by greater heat impact at the edges of the cut.

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