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COURSE OF HEAT AFFECTED ZONE DEPTH IN THE CROSS SECTION SAMPLE AFTER WEDM CUTTING

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ABSTRACT:
The article deals with detailed evaluation 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. 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. The aim of this paper is to describe real course of micro-hardness in particular cross-sections, and to give recommendations concerning adjustment of main technological parameters in a way to achieve *HAZ* homogenity along the whole cut.

KEYWORDS:
Cutting current, micro-hardness, heat affected zone (*HAZ*), numerical methods, technological parameters, Surface roughness, wire electrical discharge machining (*WEDM*).

1. INTRODUCTION

The *HAZ* depth and its course are closely tied to operating life of components produced by this progressive technology. Exceptionally liable to this effect are shear tools where undesirable *HAZ* influence can decrease operating life by 20%. The unwanted effect is caused by so called white layer that is formed by structure after secondary hardening as a result of electroerosion process. Nevertheless, we should be cautious concerning this statement too, since certain analyses of white layer properties draw attention to the fact that in some phase of parts operating life the white layer can possibly have positive effect on operation properties and surface functionality. Understanding and consecutive control of the process would make it possible to create surface layers with pre-defined quality. In all other cases the white layer is characterized as an adverse phenomenon that indicates intensive high temperature impact on the surface. Following rapid cooling together with extreme or even critical adjustment of technological parameters of *WEDM* cutting can lead to creation of burn-off cracks.

2. CHARACTERISTIC OF SAMPLES´ ERODED SURFACE

Surface quality evaluation is a complex process, so in order to keep it objective, it is necessary to take into account specific properties of *WEDM* technology. Evaluated parameters are roughness, surface hardness variability and *HAZ* depth [5].

Experimental cuts were produced by wire electroerosion cutter machine AGIECUT DEM 200 (Fig. 1).

FIGURE 1. WIRE ELECTROEROSION CUTTER MACHINE AGIECUT DEM 200

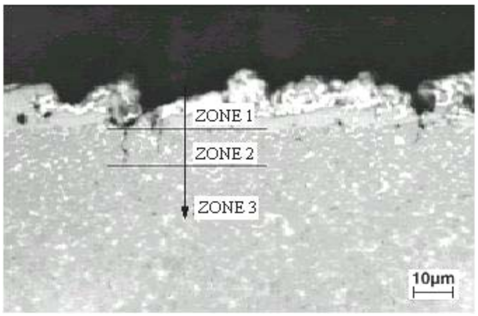

FIGURE 3. HEAT AFFECTED ZONE OF THE SAMPLE AFER WEDM CUTTING

High quality of surface is favorably 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.

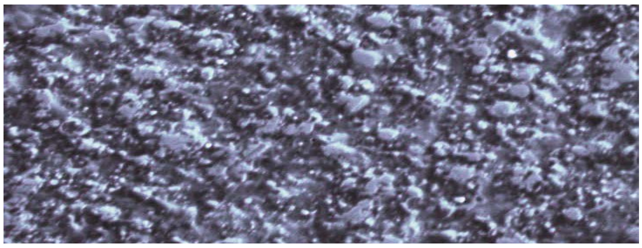

FIGURE 2. SAMPLE SURFACE AFTER ELECTROEROSION CUTTING PROCESS (500X MAGNIFICATION)

Figure 2 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.

Overall depth of impact on yet unmachined surface ranges from 10 to 30 μm.

3. PREPARATION OF EXPERIMENTAL SAMPLES

Experimental samples were made from steel EN ISO 9679 X210 CR12 (STN 19 436). It is chrome steel with 2% C and 12% Cr, used for production of moulds and cold-shearing tools. Before electroerosion cutting the metal block was oil-hardened to approx. 65 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 [3].

4. INFLUENCE OF MAIN TECHNOLOGICAL PARAMETERS ON THE QUALITY OF CUT

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 [6].

TABLE1. Basic technological parameters infuencing micro-hardness and their adjustment ranges applied in experiment

Technological parameter	Adjustment range of technological parameters		Influence on *HAZ*
	for material thickness 10 mm	for material thickness 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 gap extends, cutting speed and *HAZ* increases.
OFF time pulse "t_d" [μs]	1 ÷ 4	0.1 ÷10 μs	With growing "t_d" shape inaccuracy appears and *HAZ* degrades.

5. METHODOLOGY OF EXPERIMENTAL MEASUREMENT

Experimental values of depth and degree of *HAZ* can be determined by micro-hardness measurement in affected zone on the sample surface. In *HAZ* evaluation it is very important to respect possible scattering of micro-hardness values with regard to cut material structure. Since micro-hardness course is not identical along the whole cut, methodology was proposed for measurements in several planes near each other in different directions, while in every depth the mean micro-hardness value is to be determined.

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.

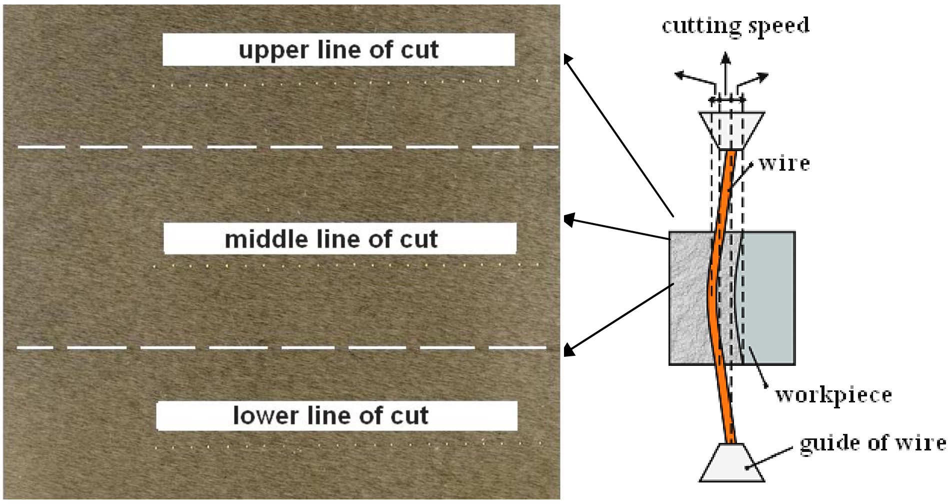

FIGURE 4. EXPERIMENTAL MEASUREMENT OF *HAZ* DEPTH

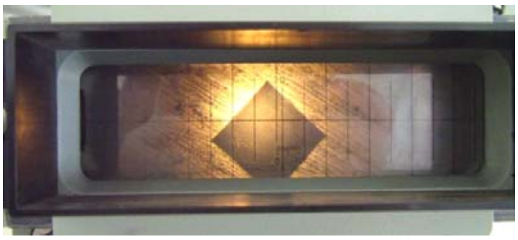

FIGURE 5. A LOOK INTO LENS OF HPO 250 VICKERS HARDNESS TESTER

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 [5].

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

$$y = f(x_1, ..., x_m) \tag{1}$$

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:

$$y = a_{00} \, . \, a_{10}^{x_1} \, . \, a_{01}^{x_2} \, . \, a_{11}^{x_1 x_2} \tag{2}$$

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 (2), which is function with seven variables, it can be written in the form:

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

that is, it approximates n-tuple of measured values $\lfloor I_i, t_i, h_{HAZ_i} \rfloor$ with functional relation

$$h_{HAZ} = f(I, t, \boldsymbol{A}) = f(I, t, a_{00}, \ldots, a_{rr}) \tag{4}$$

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

$$S(A) = \sum_{i=1}^{n} \left[h_{HAZi} - f(I_i, t_i, A)\right]^2 \tag{5}$$

reaches its minimum. In this case the unknown is matrix of variables a_{ij}.

Diagram 1 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 [8].

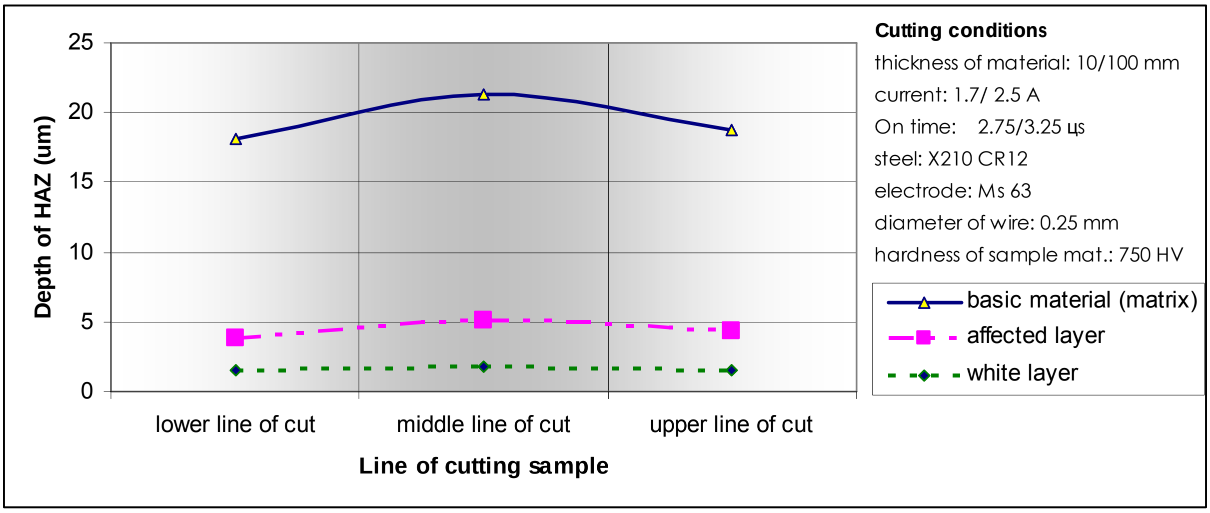

DIAGRAM 1. MEASURED VALUES OF *HAZ* DEPTH IN THE THREE LINES

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:

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

correlation index is R^2=0,9887

where h_{HAZ} – *HAZ* depth [μm]

I – cutting current [A]

t – On time [μs]

7. CONCLUSIVE EVALUATION OF THE EXPERIMENT

The aim of the experiment was observation of the size and quality of heat affected zone (*HAZ*) at electroerosion cutting with brass wire electrode. The course of *HAZ* in cutting tool axis was observed in perpendicular direction in three lines. First line was in upper part of the cut, second line was in the middle and third in lower part of the cut. Experimental observation of *HAZ* depth showed different values of affected zone in particular lines. 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.

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