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INVESTIGATION ON THE SURFACE QUALITY OF BÖHLER S290 POWDER METALLURGICAL TOOL STEEL AFTER WEDM MACHINING

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Abstract

Nowadays, there is a growing demand for fast, accurate and precise tool manufacturing. At the same time, the requirements for the quality of tool steel materials have also increased. Increasingly, tools are being made from high alloyed, highest purity, segregation free, homogenous and high hardness materials. These materials are difficult to machine with conventional technology. For this problem a solution could be the electrical discharge machining technology (EDM). During the EDM process an electrical discharge occurs between an anode and a cathode in a dielectric medium [1]. The EDM process is characterized by high heat, that cause structural changes on the surface of the machined materials. In EDM process the surface of the machined material is eroded by melting and evaporation due to large quantity of heat [2]. This paper presents a study of the wire EDM machining surface of S290 PM HSS materials with different parameters performed by multiple cutting. The aim of this investigation was to find the optimal parameters and trim cuts number for the efficient production of the tools from S290 HSS PM materials with the required surface quality.

Keywords*:* *high speed steel, electrical discharge machining, surface quality, surface roughness, scanning electron microscopy.*

Introduction

Wire Electrical Discharge Machine (WEDM) is another form of electrical discharge machining which is now used for machining in case of high alloyed, high hardness and high strength tool steels [3]. WEDM has lot of applications, for instance, in the machining of various cold work tools, hot work tools, press tools, dies, high speed tools, in aerospace industry, automotive and medical industry. The WEDM process is an electrical discharge between an anode and a cathode in dielectric medium. The anode is a wire electrode usually made from cupper, and the dielectric liquid is a deionized water. The surface of the machined material is eroded by melting and evaporating. The outer layer of the workpiece can reach 12000°C temperature where the material melts and evaporates locally. The molten metal droplets are flushed by the dielectric liquid (Fig. 1).

During the WEDM machining process the high heat energy has a negative effect to the surface of the material. On the material surface are developing a heat affected zone with different surface morphology. This surface consists white layer with hollow cavities, micro-cracks and craters [4-6]. White layer is a hard skin on the WEDM machined material surface formed due the resolidification of melted residual material which was not completely flushed by the dielectric

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liquid [7]. To be better the surface quality, de defects and the geometrical inaccuracies of the WEDM machined materials the manufacturers are used more trim cuts after rough cut [8].

The parameters of the WEDM process affect greatly the surface quality of the materials. Therefore, it is very important to determine the right parameters for each raw materials quality [9].

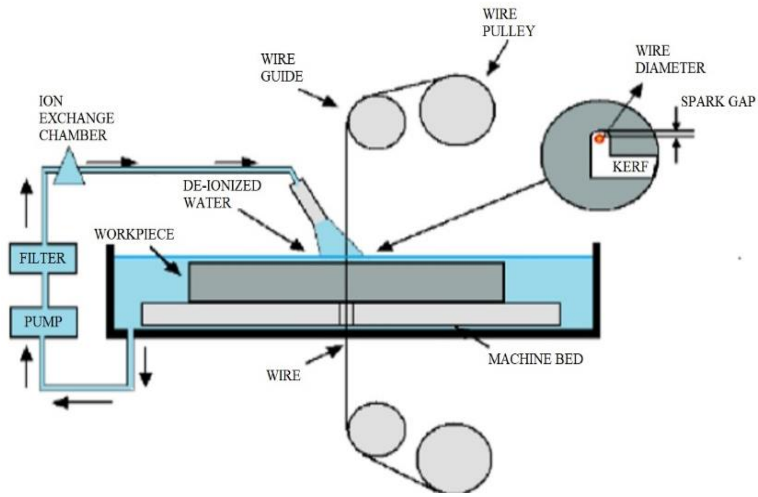


Fig 1. Schematic the WEDM process

The process parameters are used to control the performance measures of the machining process. The mainly parameters are: pulse on time (TON), pulse off time (TOFF), peak current (IP), wire speed and wire tension.

Pulse on time (TON): in this time the electrical discharge are working between the wire and workpiece. Wire breakage may be caused by higher value of electric discharge.

Pulse off time (TOFF): no voltage is supplied during this time. Between workpiece and wire electrode is not electric discharge [10].

Peak current (IP): the peak current plays a vital role in WEDM. The unit of measurement is amper. During TOFF time, the current increases until it reaches a present level, which denoted as the IP. In roughing operations higher amperage is used [11].

Wire speed: it is also significant parameter in WEDM. If speed of wire increases, the wire dissipation and machining cost will increase while wire breakage occurs of low wire speed.

One of the mainly important factors, that characterizes the quality of WEDM machined surfaces is the roughness. The surface roughness value must to be minimalized. It is important to the finish trim cut of WEDM. The main important factors who are affected the surface roughness are the peak current and the pulse on time (TON) [12].

In addition to the formed surface roughness, the cutting parameters also influence the development of the surface layers. The machined surface consists of three separable layers, the uppermost layer formed from the molten residual droplets (white layer), below which the heat affected zone (HAZ) is formed, and the third part is a basic material, which does not change during machining. The surface quality is largely affected by the thickness of the white layer. The thickness of the white layer also depends on the polarity. Using negative polarity instead of positive the white layer thickness could be reduced [13].

Some research compares the chemical composition of the surface on the pre-WEDM machined and post-WEDM machined material and found that the initial C or Cu content was multiplied in the surface layers after the WEDM process [14].

During WEDM machining superficial structural changes take place on the workpiece surface. This surface modifications influence the performance of the machined tools and increase the cost [15].

In the present study, I examined the surface quality changes in case of Böhler S290 PM tool steel machining with WEDM multiple cuts using different parameters.

Materials and experimental methods

A high-speed steel grade S290 Microclean produced by powder-metallurgy methods was machined with WEDM using different machining parameters with multiple trim cuttings. The chemical composition of the steel is presented in table 1.

Table 1. Chemical composition of the S290 Microclean PM high-speed steel (mass%)

Elem.	C	Si	Mn	Cr	Mo	V	W	Co	Fe
%,wt.	2.1	0.48	0.31	3.9	2.6	5.2	14.5	10.9	balance

The Böhler S290 Microclean high-speed steel is produced by powder metallurgic methods provided isotropic, homogenous and segregation-free properties to the raw material. This grade of steel has the high hardness, high compressive strength and good wear resistance. The powder metallurgical technology gives to this material very good toughness.

The prefabricated materials were annealed to 320HB on delivery condition. After it the materials were cryogenic quenched in vacuum furnace and three times tempered to 68HRC. This was followed with WEDM machining.

The WEDM machining were performed on an Charmilles machine, model FI 240 SLP (Fig. 2).

Fig. 2. Charmilles FI 240 SLP Electroerosion equipement

The materials were put in a dielectric liquid which are deionized water. The eroded powders from the machined steel as well as the wire tool cupper electrode were flushed with a stream of dielectric fluid. During the cutting I used a 0,25mm diameter electrolyte cupper wire.

The machining parameters used for multiple cuts are shown in Table 2.

Table 2. Machining parameters

Cutting step	Peak current (A)	Pulse on time (μs)	Pulse off time (μs)	Ful offset (mm)
Rough cut	21	0.7	7.4	0.12
Trim cut 1	23	0.2	3.8	0.13
Trim cut 2	7	0.4	3	0.13
Trim cut 3	7	0.4	3	0.13
Trim cut 4	7	0.2	3	0.13
Trim cut 5	7	0.2	3	0.13

On the WEDM machined parts surface roughness measurements were performed. The MahrSurf GD120 machine was used to measure the roughness of the machined surface (Fig. 3).

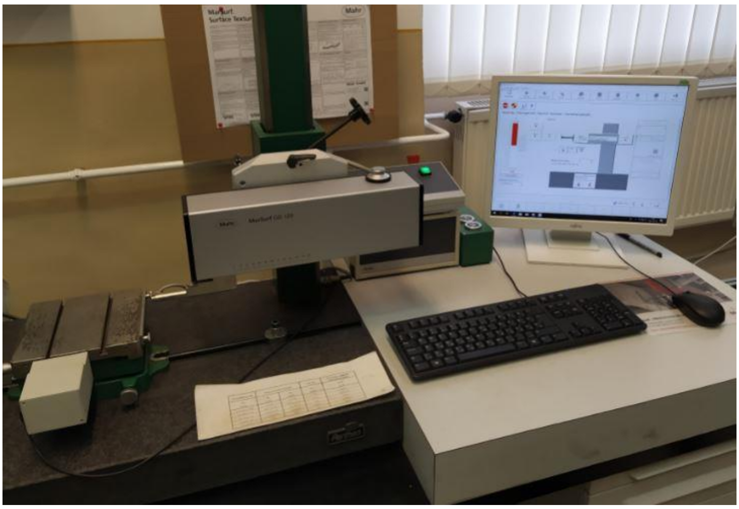


Fig. 3. MahrSurf GD120 roughness measuring machine

It was measured:

- the general surface roughness (eq. 1):

$$R_a = \frac{1}{l}\int_0^l |Z(x)|dx \tag{1}$$

- the R_z (eq. 2):

$$R_z = \frac{1}{n}\left(\sum_{i=1}^{5} p_i - \sum_{i=1}^{5} v_i\right) \tag{2}$$

The electron microscopic examinations of the machined surface were performed with a Jeol scanning electron microscope type JSM5310 (Fig.4).

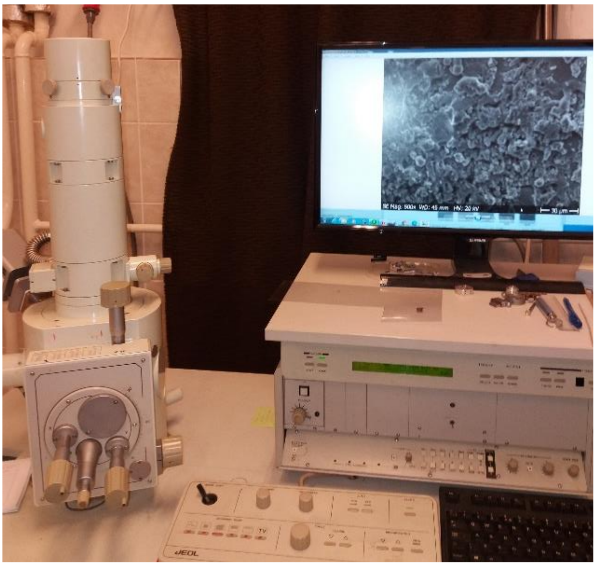


Fig. 4. Jeol JSM5310 SEM

Results and Discussions

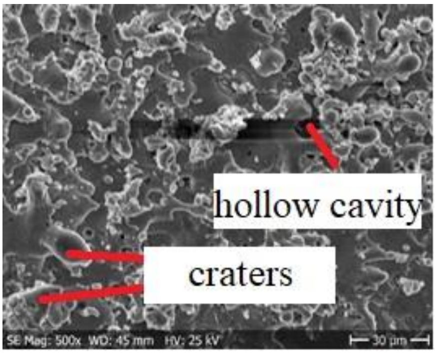
The WEDM process generated an intense heat between the wire electrode and workpiece surface causing localized melting and evaporation of the material. Experimental pieces after the different trim cuts were subjected to the roughness of the machined surface, the parameters R_a and R_z are presented in Table 3.

Table 3. The roughness parameters of the WEDM machined S290 steel

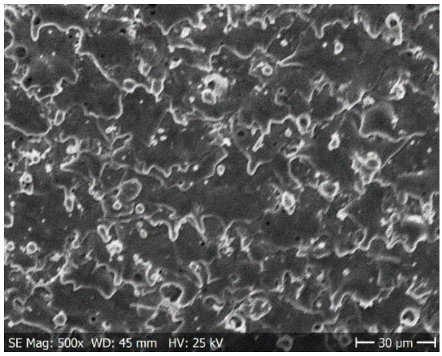
Trim cuts nr.	Ra (µm)	Rz (µm)
1	2.49	15.3
2	1.00	7.1
3	0.99	7.0
4	0.68	5.1
5	0.49	3.9

After the roughness measurement it can be stated that as the trim cut increased both surface roughness parameters value are decreased. The values of the R_a and R_z after the first trim cut decrease significant, but further decreases only slightly. It can be observed, that the roughness decreases as the current decreases. Based on the roughness measurement results this means that for S290 PM material quality with the applied machining parameters must be sufficient one trim cut for a good surface quality.

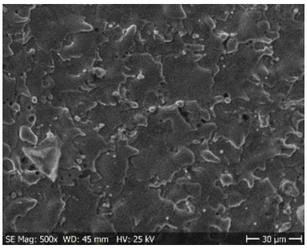
The scanning electron microscope (SEM) images for different trim cut workpieces are presented on Figure 5. The first picture show the SEM picture after the first trim cut at 500x magnification. On the morphology of the surface, we could see the craters and cavities.



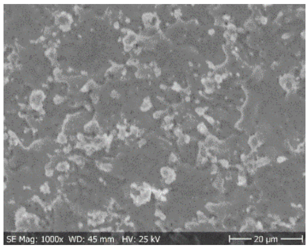
Micrograph after first trim cut



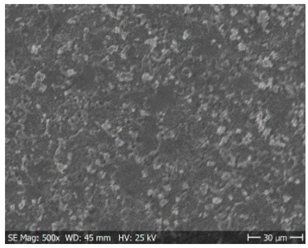
Micrograph after the second trim cut



Micrograph after the third trim cut



Micrograph after the fourth trim cut



Micrograph after the fifth trim cut

Fig. 5. Scanning electron micrographs of the quality S290 after different WEDM trim cuts

The following images show the WEDM surfaces after the additional trim cuts. it can be observed, that after the first trim cut the craters and cavities are much smaller. The fact, that no microcracks have formed due to the high heat effect can be considered as a clean and homogenous raw materials quality and the good heat treatment.

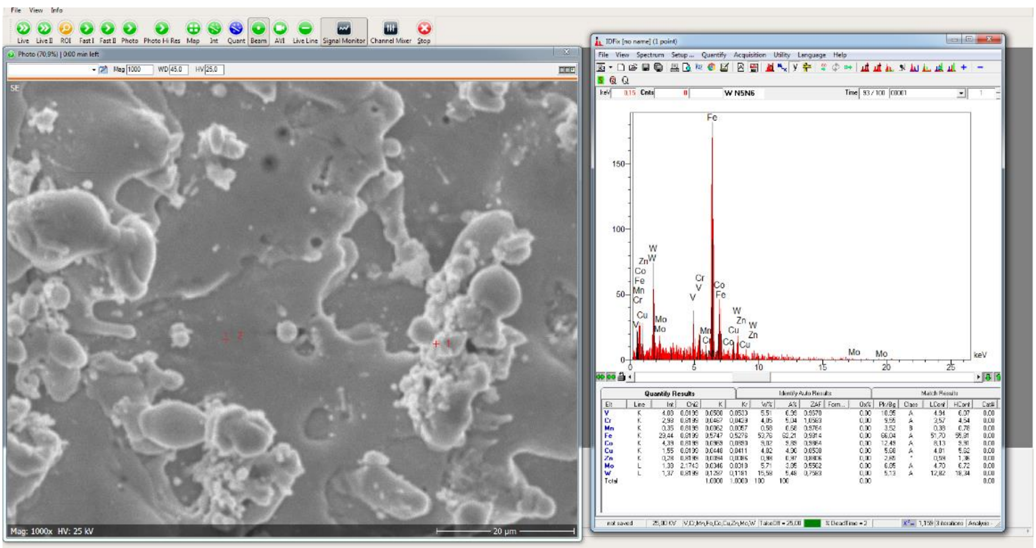


Fig. 6. Scanning electron micrograph and Energy Dispersive X-Ray Spectroscopy (EDS) after the first trim cut

The picture from Fig. 6. A with 1000x magnification show the WEDM trim cut material surface with “white layer”, craters and cavities and the EDS Analyses from this surface present the semi-quantitative elements from a specific location of interest. From the EDS Analyses it can be seen that in addition to the usual composition of the tested material quality, copper and zinc is also present in the composition. This is due to the fact, that copper and zinc from the wire electrode have melted onto the material surface.

Conclusions

The investigation focused on the Böhler S290 PM tool steel surface changes as an effect of WEDM machined with different trim cut. Due to the high temperature and the electrical discharges formed a cratered texture on the material surface, which is clearly visible on the first trim cut SEM image. After the fifth trim cut the crater texture almost disappeared.

Based on the EDM analysis of the investigated surface, after the first trim cut, the presence of W, Co, Cr, V, Mo on the surface and Cu and Zn can be observed. The Cu and Zn presence can be attributed to the melting form the wire electrode.

Based on the surface roughness measurement, it can be clearly stated that under the effect of the trim cut, but even after the second trim cut a fine, small roughness surface is obtained. In practice, the expected surface roughness is determined by the tool use. The “white layer”, the craters, melted copper and zinc are usually removed by fine grinding and polishing.

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