EVALUATION OF SURFACE QUALITY OF X210CR12 STEEL FOR FORMING TOOLS MACHINED BY WEDM

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The stressed parts of forming tools are usually made of tool alloy steel X210Cr12 with additional thermal treatment. When machining these parts, due to the high demands on shape and precision, wire electrical discharge machining (WEDM) is used, which a method is belonging to the group of non-convention machining technologies. WEDM uses physical principles to cut material, which enables for machining parts which were already thermally treated. The long-term trend of improving precision and quality of the machined surface leads to the necessity of its thorough studying. This study concerns itself with evaluating the morphology of the worked surface using electron microscopy (SEM) and chemical composition analysis (EDX). The focus was to evaluate the quantity of the adhered material from the brass wire electrode. Furthermore, surface and profile parameters of the machined surface were studied using Atomic force microscope (AFM). Samples for the experiment were made of X210Cr12 steel, which was treated with 4 different thermal treatments.

KEYWORDS

WEDM, electrical discharge machining, steel X210Cr12, quality of surface, Analysis of the chemical composition

1 INTRODUCTION

Electrical discharge machining does not use mechanical energy to part material, but instead it uses physical principles. This allows for machining of any at least a bit conductive material. WEDM technology, whose schematic is in Fig. 1, gained wider use with the introduction of new construction material for automotive and aircraft industry [Ghodsiyeh 2013], [Kozak 2004].

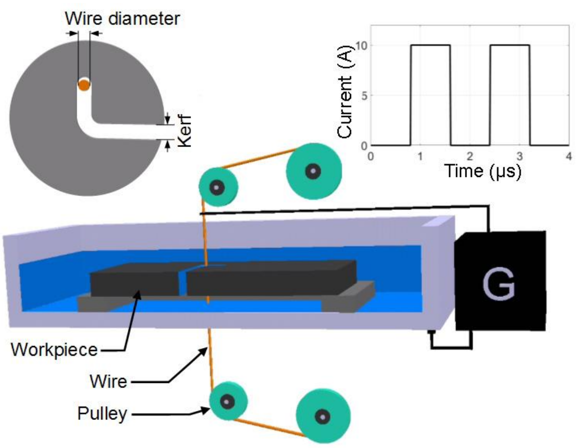

Figure 1. Scheme of the wire electrical discharge machining process

There are many factors which can have major effects on the quality of the machined surface and can be found using various methods [Matoušek 2009], [Matousek 2010]. Even though the machine settings parameters are a significant factor, it is the characteristics of the workpiece material which define the resulting surface quality. The quality parameters of the surface are influenced by an array of physical and mechanical characteristics of the material along with the type of its heat treatment. Usage of the full potential of the final wire electrical discharge machining is very difficult taking into account the high number of possible varying parameters.

2 EXPERIMENTAL SETUP AND MATERIAL

The samples for the experiment were made of tool alloy steel for cold work X210Cr12. The chemical composition is in the Tab. 1. This material characterized by high resistance against abrasion and strength of 800-850 MPa. It is very dimensionally stable after hardening, but has considerably low toughness, especially in transverse direction. It is mainly used for very highly stressed tools with high performance and longetivity used for shearing and hole-punching of metallic materials of low thickness (up to 4 mm). For the experiment, the semi-product was a prism 15 mm thick.

Contents	C	Si	Mn	P	S	Cr
Min (wt. %)	1.9	0.1	0.2			11
Max (wt. %)	2.2	0.6	0.6	0.03	0.03	13

Table 1. Chemical composition of steel X210Cr12 as prescribed by norm

The material for making the samples was heat treated according to Tab. 2. Heat treatment was mainly carried out for the purpose of changing the grain size and hardness of material. The various heat treatments were chosen so the samples would encompass both low and high hardness, with the latter being used mainly for punches of tools used for cold forming. To measure the hardness, a hardness tester ZHR 4150AK supplied by Zwick Roell, production series Rockwell, was used.

Number of sample	Heat treatment (HT)	Hardness (HRC)
1	780 °C/ 20 hours / cooling in a furnace	11.6
2	Quenched and tempered, 960 °C / 1 hour / oil 200 °C / 2 hours / air	59
3	Quenched 1100 °C / 1 hour / oil	41
4	Soft annealed 760 °C / 2 hours / furnace	13.1

Table 2. Thermal treatment type of individual samples

The WEDM machine used in this study was high precision five axis CNC machine MAKINO EU64. As electrode, brass wire (60 % Cu and 40 % Zn) PENTA CUT E with a diameter of 0.25 mm was used. Samples were immersed in the deionized water which served as dielectric media and also removed debris in the gap between the wire electrode and workpiece during the process. The dielectric flushing pressure was for all samples 5 kg/cm^2. Each sample was machined under the same set cutting parameters. These parameters were set according to the manufacturers recommendations for said material of said thickness. For achieving the highest possible precision of dimensions and quality of the machined surface, every sample was cut by 4 cuts. The setting of machine parameters pulse on time, pulse off time, gap voltage, wire speed and discharge current for each cut is in Tab. 3.

	Gap voltage (V)	Pulse on time (µs)	Pulse off time (µs)	Wire speed (m/min)	Discharge current (A)
Cut 1	40	9	44	15	29
Cut 2	30	2	40	10	13
Cut 3	30	2	42	10	11
Cut 4	80	1	3	10	1

Table 3. Machining parameters used in the experiments

3 RESULTS OF EXPERIMENT AND DISCUSSION

The machined surfaces of samples were cleaned off in an ultrasound cleaner and studied using an electron scanning microscope (SEM) LYRA3 supplied by Tescan company. This machine comes equipped with an energy-dispersion detector of X-rays, which enabled for studying the changes of chemical composition of the surface caused by WEDM machining. The surface topography, surface and profile parameters were further studied using a non-contact 3D profilometer Taylor Hobson Talysurf CCI Lite. The measured data were then processed using TalyMap Gold software, which allowed creating a 2D and a 3D model of the analysed surface. Microscope Dimension Icon supplied by Bruker Company was used to study the sample surface morphology using a semi-contact technique Atom force microscopy (AFM). The measured data was analyzed using the Gwyddion software.

3.1 Analysis of the sample surface morphology and chemical composition EDX

The surface of samples machined by wire electrical discharge machining is covered with a number of craters created by individual electrical discharges. The morphology of thusly created surface is dependent not only on the settings parameters of the machine, but mainly on the worked material and its additional heat treatment. The machined surfaces of materials Inconel 706 [Sharma 2015], $Ti_{50}Ni_{50-x}Cu_x$ [Manjaiah 2015], steel HSLA [Azam 2016] or pure titanium [Kumar 2013] are covered with the adhered globule of debris, which were not swept away by the stream of dielectric liquid. Surface of materials Inconel 718, titanium alloy Ti-6Al-4V and others can contain surface micro-cracks which can later initiate formation of more extensive cracks [Aspinwall 2008].
Morphology of the machined surfaces is in Fig. 2. No machined samples shown any cracks or adhered globule of debris. The surface of sample 1 and 4 (see Fig. 2. (a, d)) was covered with a more coherent layer of molten and then cooled material, than the other 2 samples, on which presence of minor craters was studied.

During the WEDM machining, intensive diffusion processes take place due to very high local temperature (10 000 °C to 20 000 °C) [McGeough 1988], during which the completely molten workpiece material mixes with the tool electrode material. After its cooling by the dielectric fluid, a so called „stuck-on" adheres to the machined surface, which is made of copper and zinc from the tool electrode as well as from the workpiece elements. Thickness of this „stuck-on" is influenced not only by the settings parameters of the machine, but also by an array of mechanical and physical properties of the machined material [Huang 2003, Newton 2009].
Local chemical composition analysis has been carried out on the machined sample surfaces, each in an area of 200x200 µm. The results of this EDX analysis were put into Tab. 4.

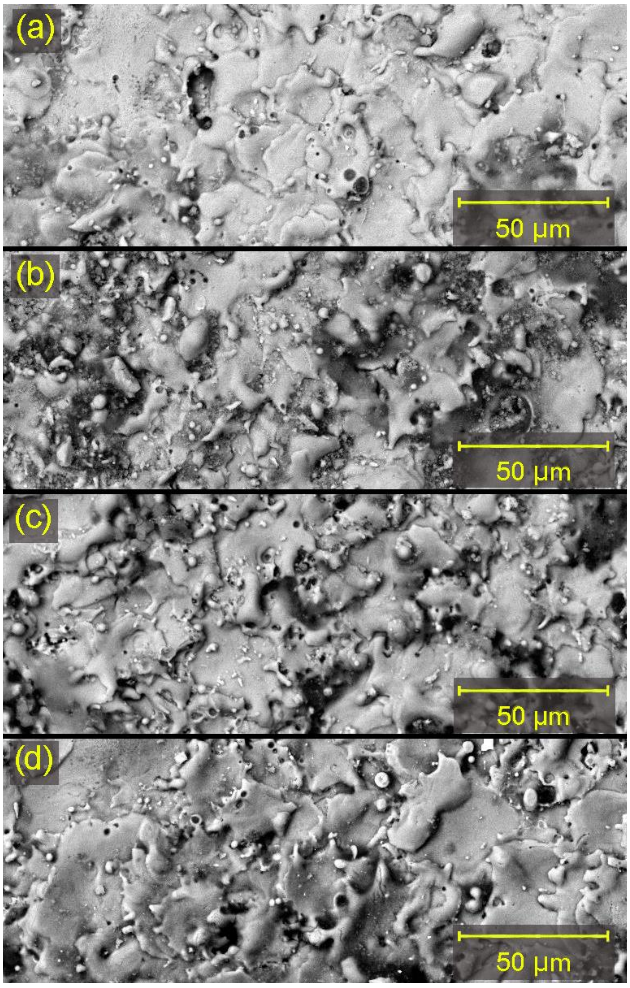

Figure 2. Sample surface morphology (SEM) magnified 1 000x (a) sample 1, (b) sample 2, (c) sample 3, (d) sample 4

Number of sample	Fe (wt. %)	Cr (wt. %)	Cu (wt. %)	Zn (wt. %)
1	85.9	12.5	1.2	0.4
2	88.5	10.4	1.1	
3	88.9	10.5	0.6	
4	88.5	10.6	0.5	0.4

Table 4. Measurement of chemical composition on surface of samples

As a result of all the samples being cut in 4 cuts, a significant removal of „stuck-on" and reduction of the adhered zinc and copper from the wire electrode took place on all studied samples. Highest amount of copper and zinc was detected on sample 1, as observable from Fig. 3.

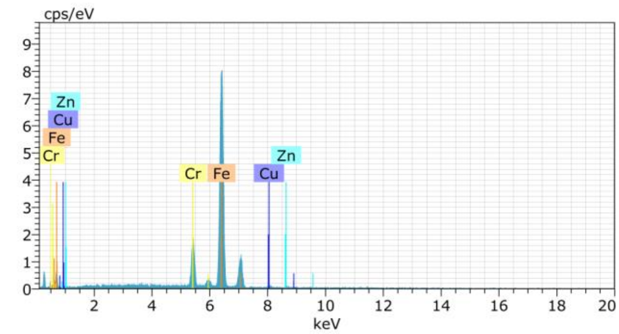

Figure 3. Chemical composition analysis of sample 1

3.2 Topography analysis of sample surfaces

Parameters processed using the profile method were arithmetical mean deviation of profile (Ra), maximum height of profile (Rz) and root mean square deviation (Rq). Surface method examined parameters arithmetical mean height (Sa), maximum surface height (Sz) and root mean square height (Sq). The surface parameters allow evaluation of the surface in all aspects that are technically significant. In planar evaluation of surface quality it is possible to construct the overall shape of the surface, overall texture and so better predetermine the functional properties of surfaces in operation. [Jiang 2012], [Waikar 2008].

Profile parameters were evaluated on 1024 profiles of a single evaluation length lr=0.8 mm obtained from S-F surfaces of measurements made with the 20x objective. The values of both surface and profile parameters evaluated on surfaces of individual samples were put into Tab. 5.

Number of sample	Ra (µm)	Rq (µm)	Rz (µm)	Sa (µm)	Sq (µm)	Sz µm)
1	1.29	1.57	7.68	1.38	1.7	15.3
2	1.28	1.56	7.6	1.35	1.66	15.27
3	1.43	1.83	10.49	1.65	1.99	21.8
4	1.32	1.68	8.8	1.36	1.76	16.34

Table 5. Evaluated **planar** and profilic parameters of individual samples

The lowest assessed mean arithmetic deviation and its surface equivalent was on sample 2, whose 3D picture is in Fig. 4. Conversely, the highest values of Ra and Sa were assessed on sample 3, which shown toughness of 41 HRC.

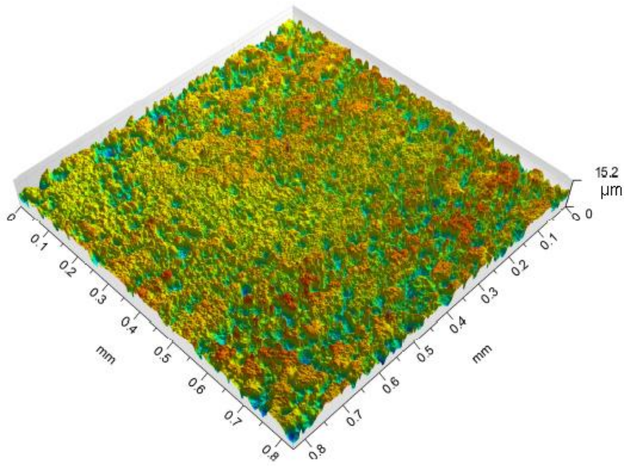

Figure 4. 3D colour-filtered shot of sample 2 surface

3.3 Analysis of morphology using AFM

The morphology of machined surfaces was further analyzed by a semi-contact technique AFM, which is based on detection of changes in interaction forces between a probe and the surface of the workpiece along with changes of distance between the probe and the surface. Measurement was performed in Scanasyst mode and a probe with a 0.65 µm diameter was used. The evaluated area had dimensions of 40x40 µm. A detailed morphology of the wire electrical discharge machined surface of the sample is displayed in Fig. 5.

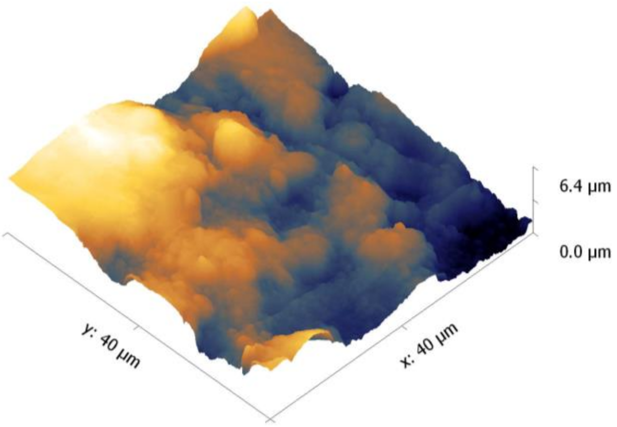

Figure 5. Morphology of sample 4 surface (AFM)

4 CONCLUSIONS

Through means of various analysis of samples surfaces machined by wire electrical discharge machining cutting in 4 cuts, with the samples being made of tool alloy steel X210Cr12 with 4 different heat treatment types, these conclusions were found:

- neither globule of debris nor micro-cracks were detected on any of the machined samples surfaces,
- the surface of sample 1 (11.6 HRC) and sample 4 (13.1 HRC) were covered with a more coherent layer of completely molten and then cooled material than the other 2 samples, on which a number of minor craters was studied,
- local microanalysis of chemical composition showed very small amounts of defunded elements (copper, zinc) from the brass electrode, peaking at 1.6 wt.% (sample 1),
- lowest values of all studied profile and surface parameters were found out in sample 2 (59 HRC).

The aforementioned conclusions clearly show that morphology and topography of wire electrical discharge machined surfaces very heavily depend on mechanical parameters of the machined material which are positively set by the basic micro structural parameters after specific heat treatment of the sample.

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