EXPERIMENTAL EVALUATION OF THE QUALITY OF SURFACE AFTER WEDM FOR STEEL X210CR12

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Wire electrical discharge machining (WEDM) is a non-conventional machining technology which uses electrical impulses between two electrodes to cut materials. The long-term trend of increasing accuracy and surface finish quality leads to the necessity of its detailed examination. The study deals with the evaluation of the surface morphology by electron microscopy (SEM) and chemical composition analysis (EDX). Object of interest was to assess the amount of adhering material from brass wire electrodes. Furthermore, it also examined surface and profile parameters of the machined surface. Samples for the experiment were made of X210Cr12, tool alloy steel for cold working, which was subject to 4 different types of heat treatment. Dependence between the amount of adherent material from the wire electrode and the the of machined material has been found.

KEYWORDS

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

1 INTRODUCTION

For material cutting, the electrical discharge machining does not use mechanical energy but the principles of physical phenomena. This allows machining of all materials which are at least minimally electrically conductive. WEDM technology gained wider application when introducing new materials that were needed for production in the automotive and aerospace industries; its scheme is shown in Fig. 1 [Ghodsiyeh 2013], [Kozak 2004].

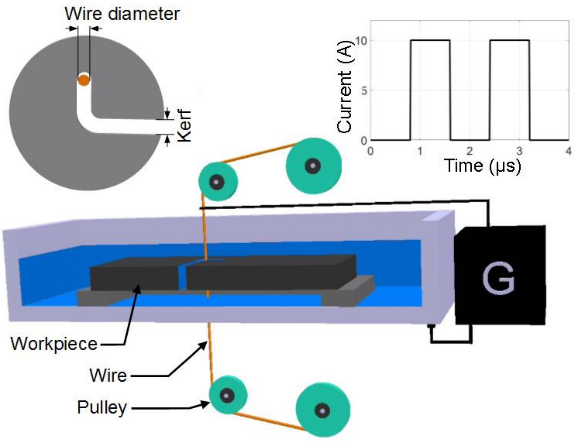


Figure 1. Scheme of the WEDM process

There are many factors that have a major impact on the quality of machined surface and can be found using different methods [Matousek 2009], [Matousek 2010], [Blecha 2011], [Blecha 2011]. Although machine setting parameters are an important factor, the workpiece finish quality is defined by its material properties. Parameters of surface quality are influenced by a set of physical and mechanical characteristics of the machined material and the type of its heat treatment.

[Tosun 2004] investigated the effect of the pulse duration, open circuit voltage, wire speed and dielectric flushing pressure on the WEDMed work piece surface roughness. It was found that increasing pulse duration, open circuit voltage and wire speed increases with surface roughness, whereas increasing dielectric fluid pressure decreases the surface roughness. [Mahapatra 2006] studied the effects of six factor include, discharge current, pulse duration, pulse frequency, wire speed, wire tension and dielectric flow rate on surface roughness and material removal rate and it was found that factors like discharge current, pulse duration, dielectric flow rate and their interactions play a significant role in surface roughness and material removal rate. [Rao 2011] had stated their effort to optimize surface roughness and it was found that, the parameters like peak current and pulse on time are most significant. Wire tension and servo voltage are significant and pulse off time, flushing pressure and wire speed are less significant factors that affect surface roughness.

2 EXPERIMENTAL SETUP AND MATERIAL

The samples for the experiment were made from tool steel alloy for cold working, X210Cr12 (Czech to European equivalent grades of CSN 41 9436). The chemical composition is in Tab. 1. This material is characterized by high wear resistance and strength (800-850 MPa). It has a good dimensional stability after quenching but very poor toughness, particularly in the transverse direction. It is mainly used for heavy-duty tools with high performance and durability, for cutting and punching of metallic materials with small thicknesses (up to 4 mm). The experiment used a semi-finished prism with a thickness of 15 mm.

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 prescribed by the norm

Material for the production of samples was heat treated as shown in Tab. 2. The heat treatment was carried out mainly in order to change the material grain size and hardness. Types of the performed heat treatment were selected so that the samples had low as well as higher hardness which is used primarily for the punches and punching dies for cold cutting. Hardness was measured by hardness tester ZHR 4150AK, Rockwell type, made by Zwick Roell. Measurements were performed at 10 different locations on the specimen surface, and consequently the mean value determined.

Number of HT	Heat treatment (HT)	Hardness
1	780 °C/ 20 hours / cooling in the furnace	91 HRB
2	Quenched and tempered 960 °C / 1 hour / oil 200 °C / 2 hours / air	60 HRC
3	Quenched 1100 °C / 1 hour / oil	42 HRC
4	Soft annealing 760 °C / 2 hours / furnace	92 HRB

Table 2. Types of heat treatment in 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. For each of the three samples made of materials with different type of heat treatment, different settings of the parameters (gap voltage, pulse on (T_{on}) and off time (T_{off}), wire feed and discharge current) were used to determine their effects on the machined surface (Tab. 3.) Values for setting individual parameters were determined on the basis of previous tests [Mouralova 2015].

Number of sample	Gap voltage (V)	Pulse on time (µs)	Pulse off time (µs)	Wire feed (m/min)	Discharge current (A)
1	50	11	50	14	28
2	50	8	55	14	25
3	50	9	40	14	22

Table 3. Machining parameters used in the experiments

3 RESULTS OF EXPERIMENT

Machined sample surfaces were cleaned in the ultrasonic bath and studied using scanning electron microscope (SEM) LYRA3 from Tescan. This unit was equipped with an energy-dispersive X-ray detector (EDX), allowing the study of changes in the chemical composition of the surface due to WEDM machining. The morphology and parameters of the surface finish were studied using a contactless measuring apparatus from Alicona. The measured data were analyzed using IF-Laboratory Measurement software supplied by the manufacturer Alicona.

3.1 Analysis of the sample surface morphology and chemical composition by EDX

The surface of WEDM, processed samples consists of plenty of craters and adhering mixed material from the melted wire electrode and the workpiece material. Surface microanalysis of the chemical composition of samples made of the material with type 1 heat treatment (780 °C/ 20 hours / furnace) is processed in Tab. 4.

Number of sample	Fe (wt. %)	Cr (wt. %)	Cu (wt. %)	Zn (wt. %)
1	74	8.6	8.1	9.3
2	72.4	9.3	7.9	10.4
3	67.9	7.7	8.6	15.8

Table 4. Measurement of chemical composition on the surface of samples made of steel with HT1

The highest content of adhering elements (Cu, Zn) from the brass wire electrode is present on the surface of sample 3 – 24.4 %. This surface consists of only a small amount of craters and is shown in Fig. 2. Predominant part of the surface contains recast deposit that filled the craters caused by electrical discharges.

The results of chemical composition analysis by EDX in samples made of steel with type 2 heat treatment (quenched + tempered) were processed in Tab. 5.

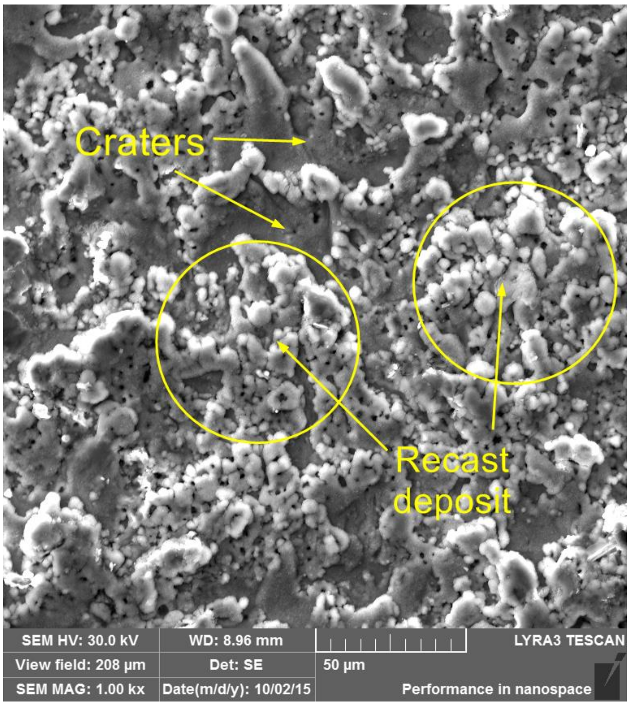


Figure 2. SEM picture of sample nr. 3 made of steel with HT1, magnified 1 000x, T_{on}=9 µs, T_{off}=40 µs, wire feed=14 m/min, current=22 A

Number of sample	Fe (wt. %)	Cr (wt. %)	Cu (wt. %)	Zn (wt. %)
1	70.1	7.9	6.8	15.2
2	65.3	7.4	5.9	21.4
3	69.6	8.7	10.2	11.5

Table 5. Measurement of chemical composition on the surface of samples made of steel with HT2

The surface of samples is covered with 22 to 27.3 % of copper and zinc, mixed with the workpiece material due to intense diffusion processes. The wire electrode contains 60 % of Cu and 40 % of Zn; however, the quenched and tempered sample material exhibits higher percentage ratio of adherent zinc than in the wire composition. The highest percentage of zinc in all 12 prepared samples occurs on the surface of sample 2 – 21.4 %. Fig. 3 a) shows the detected area which is largely covered with recast deposit. This recast deposit consists primarily of zinc as illustrated by the element distribution map in Fig. 3 b).

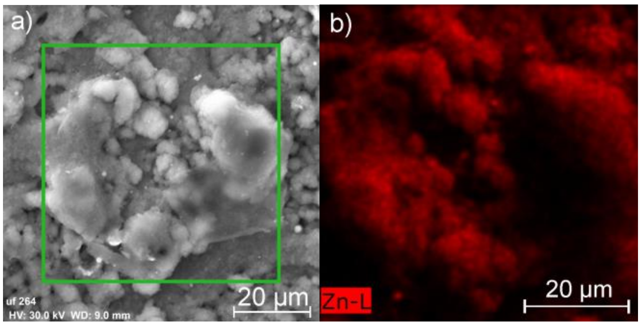


Figure 3. Chemical analysis of the surface of sample 2 made of steel with HT2 a) investigated area, b) distribution of Zn

EDX analysis of samples made of material with type 3 heat treatment (quenched) is processed in Tab. 6. The highest percentage of Zn and Cu in all 12 samples was found in sample 3 – 29.8 %. Cu percentage ratio corresponds to the chemical composition of the wire electrode; this was detected only in that sample.

Surface of sample 3 (Fig. 4) is completely covered with recast deposit; in addition to only few deep craters with a diameter of about 5 µm, the surface does not exhibit any other visible craters with smooth bottomas shown in Fig. 1.

Number of sample	Fe (wt. %)	Cr (wt. %)	Cu (wt. %)	Zn (wt. %)
1	69.9	8.3	6.8	15
2	69.1	7.6	5.2	18.1
3	63.7	6.5	16.1	13.7

Table 6. Measurement of chemical composition on the surface of samples made of steel with HT3

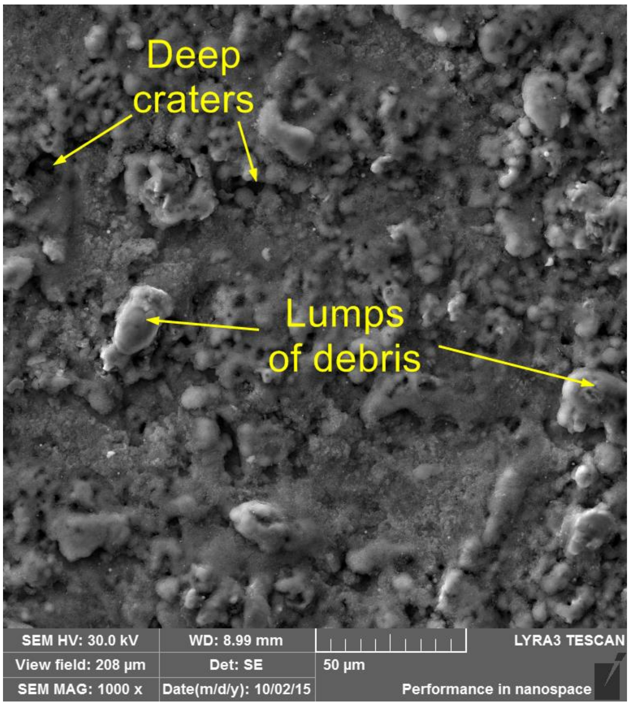


Figure 4. SEM picture of sample nr. 3 made of steel with HT3, magnified 1 000x, T_{on}=9 µs, T_{off}=40 µs, wire feed=14 m/min, current=22 A

According to EDX chemical analysis whose results are processed in Tab. 7, the smallest percentage coverage of the surface with wire electrode elements was found in the samples made of steel with type 4 heat treatment (soft annealing). Only 15 % of zinc and copper adhered to the surface of sample 2, the surface of which is shown in Fig. 5.

On the surface, it is possible to see extensive craters with smooth bottom, which consist only of the workpiece material. In the image, recast deposit was observed only in several locations.

Number of sample	Fe (wt. %)	Cr (wt. %)	Cu (wt. %)	Zn (wt. %)
1	68.8	7.9	6.2	17.1
2	75.1	9.9	3.9	11.1
3	75	8.9	7.1	9

Table 7. Measurement of chemical composition on the surface of samples made of steel with HT4

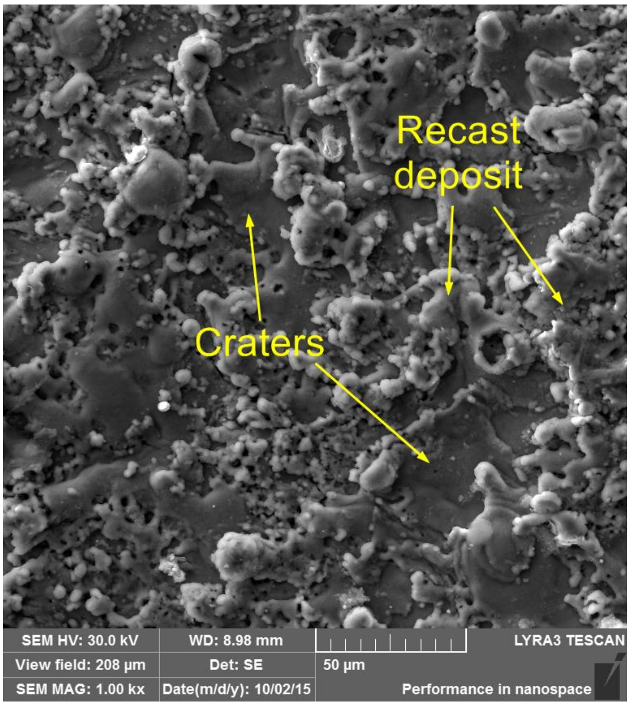
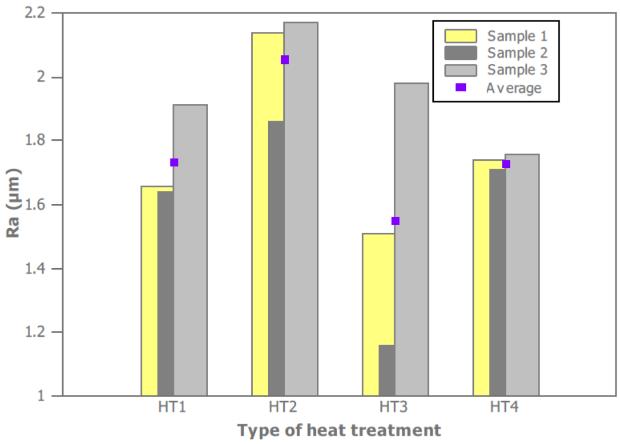


Figure 5. SEM picture of sample nr. 2 made of steel with HT4, magnified 1 000x, T_{on}=8 µs, T_{off}=55 µs, wire feed=14 m/min, current=25 A

3.2 Analysis of profile and surface parameters of the machined surface

Parameters evaluated by the profile method were as follows: arithmetical mean deviation of profile (Ra), maximum height of profile (Rz), root mean square deviation (Rq), total height of profile (Rt), maximum profile peak height (Rp), maximum profile valley depth (Rv), mean height of profile elements (Rc), mean width of profile (Rsm), skewness of the assessed profile (Rsk) and kurtosis (Rku). All parameteres were assesed on a 10 mm curve, and a 10x zoom lens were used. 5 different locations were chosen to be measured on the sample surface. The measurement was performed in conformity with the surface parameter standard ISO 21578-2 [ISO 21578-2] and the profile parameter standard ISO 4287 [ISO 4287]. When measuring the values of arithmetical mean deviation and maximum height of profile, it was necessary to take into account the limit values set by the machine manufacturer. These are: Ra up to 3.2 µm and Rz up to 20 µm for the rough cut. Measured Ra values are presented in Graph 1 which shows that all machined surfaces met the limit value given by the machine manufacturer. The lowest Ra value (1.16 µm) belongs to sample 2 made of material with type 3 heat treatment. Conversely, the highest value of arithmetical mean deviation was found in sample 2 made of material with type 2 heat treatment – 2.17 µm. The highest height of profile Rz belongs to sample 1 made of material with type 2 heat treatment (15.4 µm); the lowest height of profile was identified in sample 2 made of material with HT3 – 9.69 µm.

Surface parameters enable quantitative evaluation of the surface in all directions which are technically significant. The surface quality evaluation allows us to draw up the overall shape of the surface, the general texture, and thus better predict the functional properties of surfaces during operation [Jiang 2012]. For example, the profile evaluation uses three parameters (Ra, Pa, Wa) for arithmetical mean deviation while surface evaluation uses only parameter Sa. The surface method was used to evaluate the following parameters: arithmetical mean height (Sa), root mean square height (Sq), maximum peak height (Sp), maximum pit height (Sv), maximum surface height (Sz), kurtosis (Sku), root mean square gradient (Sdq) and developed interfacial area ratio (Sdr).



Graph 1. Ra value for individual samples

The IF Laboratory Measurement software was used to filter the surface images. An example of the filtered image of machined surface is shown in Fig 6. It is the surface of sample 3 made of steel with type 3 heat treatment and the highest Sa value (2.12 µm).

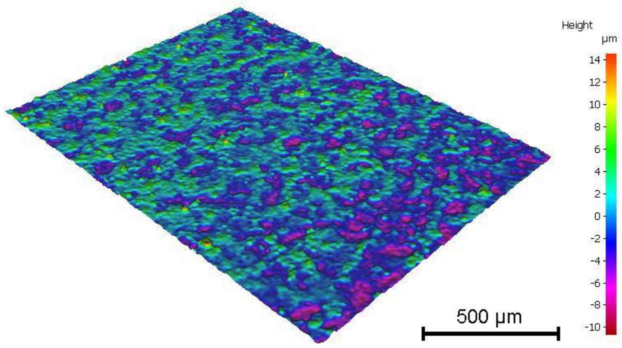
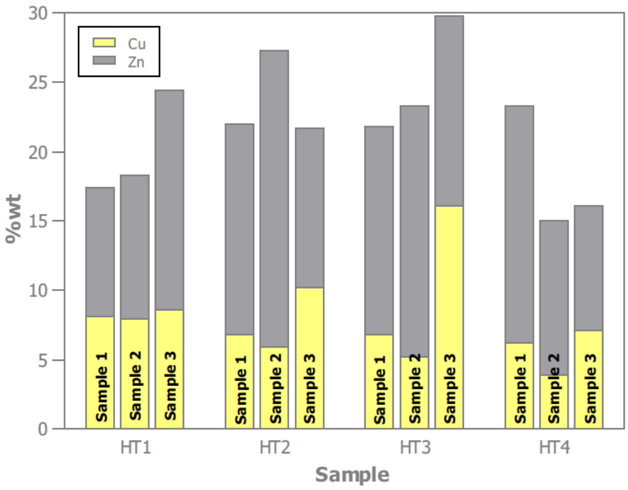


Figure 6. Colour-filtered image of the surface of sample 3 made of steel with HT3, magnified 10x, T_{on}=9 µs, T_{off}=40 µs, wire feed=14 m/min, current=22 A

4 CONCLUSIONS AND DISCUSSION

EDX analysis of chemical composition on the WEDM -processed surfaces showed the presence of mixed material from the melted wire electrode and the workpiece material, which was caused by intense diffusion processes during erosion. Mixing the material of the wire electrode with the workpiece material is in accordance with the literature [Kumar 2003], [Somashekhar 2010], [Huang 2004], [Mouralova 2016]. Amount of the adherent material from the tool electrode varies depending on the parameters of machine settings and also depending on the heat treatment type used for the machined material and its subsequent hardness. 15 to 30 % of elements from the wire electrode adhere to the surface. The highest percentage of adhering material (Cu, Zn) was observed in samples with a hardness of 59 and 41 HRc (HT2, HT3), as shown in Graph 2. More zinc than copper adheres on the most of samples, which is not in accordance with the relative chemical composition of the brass wire electrode (60 % of Cu, 40 % of Zn).

Analysis of profile and surface parameters showed the influence of pulse off time on the surface arithmetical mean deviation Ra; the lowest Ra value was observed when setting T_{off}=55 µs (samples no. 2). Conversely, the highest Ra value was observed when setting T_{off}=40 µs (samples no. 3), ranging in the interval from 1.8 to 2.2 µm. Surface with the highest measured Sa value is also the surface with the highest percentage content of adhering material from wire electrodes.



Graph 2. Amount of Cu and Zn on the surface of individual samples

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