SURFACE MORPHOLOGY OF IRON-RHODIUM ALLOY AFTER WIRE EDM

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The iron-rhodium alloy, having very interesting magnetic properties, is being studied for future use in next-gen data storage methods, for which high-speed information inscription is predicted. The examined material has been made by casting, but a for the purpose of examining its magnetic properties, the need for reducing the size of the sample arose. Because of this, wire electrical discharge machining method has been chosen, which allowed halving the sample while keeping the purity and surface properties of the original sample. This study is evaluating the morphology of the cut using electron microscopy, including microanalysis of chemical composition of the sample. Profile and area parameters were also studied, which define quality of the machined surface.

KEYWORDS

WEDM, electrical discharge machining, iron-rhodium alloy, quality of surface, Analysis of the chemical composition, EDX

1 INTRODUCTION

Wire electrical discharge machining (WEDM), is a nonconventional method which separates material using thermal effects instead of mechanical forces. Reduction of materal is achieved with periodical electrical discharges between the wire electrode and workpiece. Between individual discharges, little particles of the material are being removed and flow away in a stream of dielectric liquid [Ho 2004], [Abbas 2007]. Thanks to high temperatures in the location of the cut ranging from 10 000 to 20 000 °C [McGeough 1988], the machined material is being vaporized and therefore reduced.

Many factors can heavily influence the quality of the machined surface, and those can be found using various methods [Matoušek 2009], [Matousek 2010], [Blecha 2011a], [Blecha 2011b]. Although the settings of the machine can be of major influence, it is the material characteristics of the workpiece that define the final surface quality. The surface quality parameters are influenced by an array of physical and mechanical characteristics of the machined material [Liao 2004].

For casting of the examined sample, a vacuum induction chamber has been used, where the material is melted using inducted electrical current. This current, which progressively melts the powdered entry material, is generated in the melt by an alternating magnetic field. An advantage of this method is, first of all, a low contamination by carbon (C), nitrogen (N) and oxygen (O) in comparison to other methods. This method can generate material of purity reaching 99.9 %.

The usage of the cast sample of iron-rhodium alloy (50 % Fe + 50 % Rh) is falls within the study of magnetism, for the alloy is able to change its magnetisation based on temperature from ferromagnetic to antiferromagnetic. The change occurs when the temperature drops below 97 °C. This change is acccompanied with a rise in the ressistance from 65 μΩ·cm to 125 μΩ·cm. These changes could be used to create a new data storage medium, where with a combination of cooling, heating via passing electrical current and an external magnetic field, a high speed and density of data inscription could, theoretically, be achieved [Kudrnovsky 2015], [Marti 2014].

2 EXPERIMENTAL SETUP AND MATERIAL

The sample for the experiment was made from a iron-rhodium alloy (50 % Fe + 50 % Rh). Rhodium is a chemically very stable metal with melting point of 1966 °C. Having hardness of 1246 MPa according to Vickers, it is classified as a medium hard metal and it is a relatively good conductor of heat and electricity. Most of the produced rhodium (up to 80 %) is used in automobile industry in catalysts. It is used for producing of durable chemical dishes used for burning chemical materials at high temperatures, then in an alloy with platinum (90 % Pt + 10 % Rh) to produce thermo-electrical cells, and for producing perfect mirrors for highly demanding uses.

The semi-product used in this experiment had 50.8 mm in diameter and was 3.7 mm thick. It has been supplied by AJA International, Inc. and was 99.9 % pure. This semi-product has been cut into two discs, one 1.4 mm thick and the other 1.8 mm. Considering the dimensions of the semi-product, only magnetic clamping of the material was used.

The WEDM machine used in this study was high precision five axis CNC machine MAKINO EU64. As electrode, pure copper wire 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. Parameters of setting machine gap voltage, pulse on time, pulse off time, wire feed and discharge current (Tab. 1) were set up as recommended by the machine producer for copper material with a thickness up to 50 mm. The real cutting speed on the basis of these set parameters was 0.6 mm/min.

Gap voltage (V)	Pulse on time (μs)	Pulse off time (μs)	Wire feed (m/min)	Discharge current (A)
40	8	88	16	22

Table 1. Machining parameters used in the experiment

3 RESULTS OF EXPERIMENT AND DISCUSSION

The surface morphology, Profile and area parameters of the machined sample surface have been studied using a non-contact 3D profilometer IFM G4 supplied by the producer Alicona. The gathered data have then been processed in IF-Laboratory Measurement programme, which allowed creating 2D and 3D models of the analysed surface. The machined surface has also been studied using the electron microscope (SEM) LYRA3 supplied by Tescan. This device is equipped with energy-dispersion detector of X-rays (EDX), which allowed for studying the changes of chemical composition of the surface in regard to the WEDM.

3.1 The evaluation of the profilic and surface paremeters of the surface

Using the non-contact 3D profilometer Alicona, which is based on the principle of coherent correlative interferometry, profile parameters of the electro-erosive machined sample were determined: arithmetical mean deviation of profile (Ra), maximum height of profile (Rz) and root mean square deviation

(Rq). Using the area method determined the following: arithmetical mean height (Sa), maximum surface height (Sz) and root mean square height (Sq). The area parameters allow for quantitative examination of the surface in all directions that are technically relevant. Using this area evaluation, it is possible to construct the overall shape of the surface, general texture and therefore better predetermine the operational properties when in use [Jiang 2012], [Waikar 2008].

All parameteres were assesed on a 20 mm curve, and a 10x zoom lens were used. 5 different locations were chosen to be measured (Fig. 1) on the sample surface relative to the orientation of the disc during cutting. The assessed profile and area parameters are summarized in Tab. 2, and it is safe to say that the Ra of the machined surface was worse on all instances than with Metal matrix composites AlSi7Mg/SiC and AlSi7Mg/Al_2O_3 [Rozenek 2001], tool steel X153CrMo12 [Huang 2003a], titanium alloy Ti–6Al–4V and Inconel 718 [Aspinwall 2008] or high hardness tool steel YG15 [Huang 2013b].

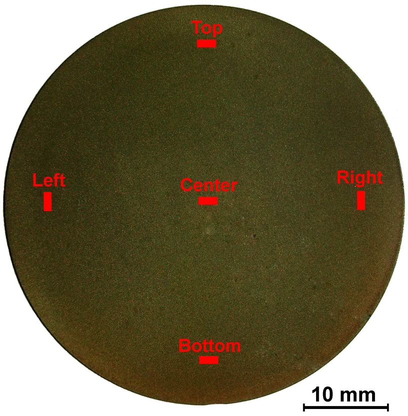

Figure 1. Measurement location profile and area parameters to the sample surface

Place of measurement	Ra (µm)	Rq (µm)	Rz (µm)	Sa µm)	Sq (µm)	Sz µm)
1 (center)	4.5	5.7	30.6	5.3	6.6	46.1
2 (top)	3.9	4.8	26.2	4.1	5.1	38.2
3 (bottom)	5.1	6.3	33.3	5.6	7	50.3
4 (right)	4.9	6.3	35.4	5	6.3	48.9
5 (left)	5	6.2	33.9	5.8	7.3	50.6

Table 2. The evaluated surface and area parameters in different locations on the sample

Of the measured locations, location 2 achieved the best results of quality, with all studied profile and area values being the lowest. In the center of the disc, where the dielectric fluid feed should be the worst however [Han 2008], the parameters are not significantly worse than on the edges. The surface topography in location 2 (top) is shown on the color filtered 3D image in Fig. 2.

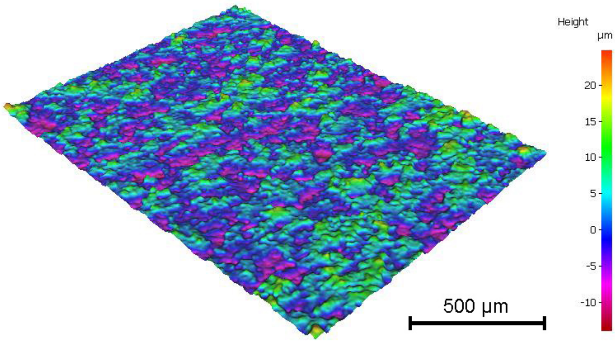

Figure 2. 3D color-filtered image surface at the point on the sample 2

3.2 *SEM analysis of surface morphology and microanalysis of chemical composition*

The surface morphology of a sample machined by WEDM is usually composed of a large number of craters and adhered mixed material from the semi-melted wire electrode and the machined material [Huang 2003, Newton 2009]. However, there are observable bottoms of craters in the sample (Fig. 3), in which the amount of difunded material from the wire electrode reaches only 9.3 wt. % (Fig. 4).

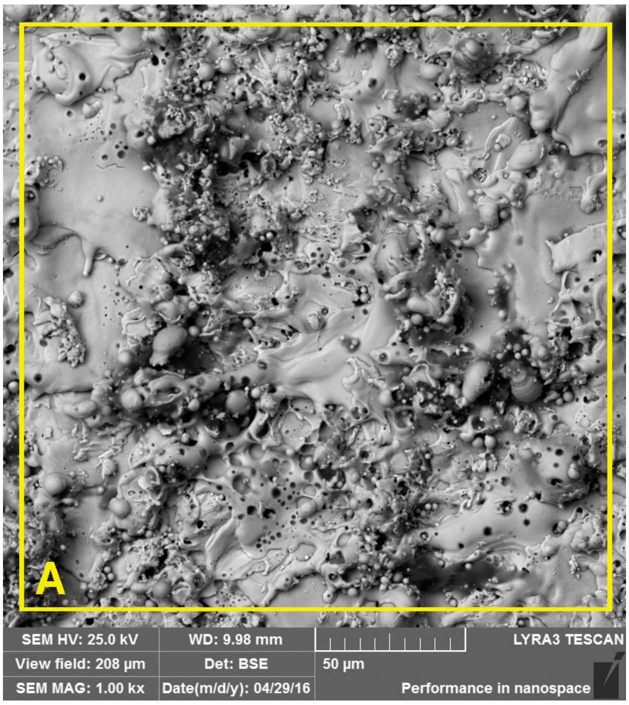

Figure 3. Morphology of surface in areas of low contamination of elements of the wire electrode (SEM), 1 000x magnification

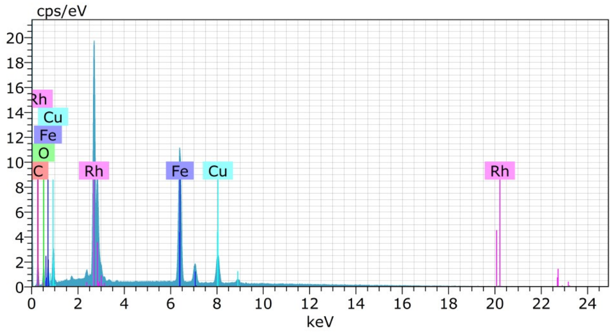

Figure 4. Analysis of the chemical composition in place A according to Fig. 3

Fig. 5 show the place, where highly intensive difuse processes between the wire electrode and the machined material took place. This place is covered by high amounts of completely melted and then cooled mixed material with 34.3 wt. % content of copper (Fig. 6). This image shows no flat bottoms of craters, the surface is rugged and shows tiny globule of debris.

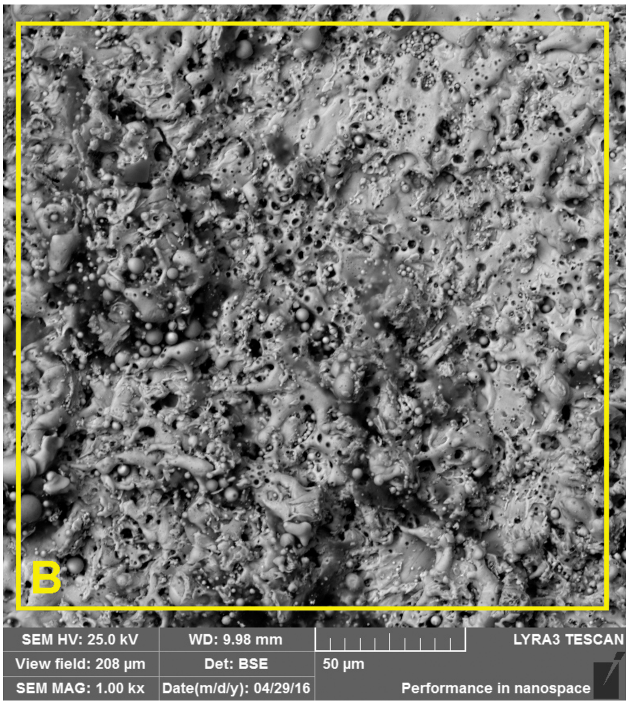

Figure 5. Morphology of surface contamination in the area of the high elements of wire electrodes (SEM), 1 000x magnification

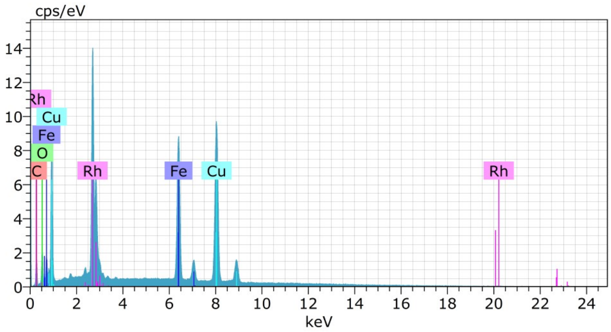

Figure 6. Analysis of the chemical composition in the area of B in Fig. 5

The results of the local chemical composition analysis in areas A and B are in Tab. 3. Both measured areas show approximately the same content of oxygen and carbon. An apparent difference is in the content of copper, with area B showing massive adheres of copper. Even though the initial ratio of iron-rhodium was 1:1m the machined surface has significantly less iron.

Place of measurement	Fe (wt.%)	Rh (wt.%)	O (wt.%)	C (wt.%)	Cu (wt.%)
A	27.8	49.8	8.4	4.7	9.3
B	17.7	34.9	7.8	5.3	34.3

Table 3. Local analysis of chemical composition by EDX in areas A and B

4 CONCLUSIONS

Although the need for machining the iron-rhodium alloy may arise rarely, but when it does arise, WEDM showed to be a suitable technological approach.

The subsequent evaluation of profile and area parameters showed that the quality of the machined surface is very low. In the 5 measured areas, Ra content varied from 3.9 to 5.1 µm and its area equivalent Sa from 4.1 to 5.8 µm. The best profile and area parameters were reached in the upper part of the worked disc, in the location near the upper guide of the wire electrode. To improve the quality of the surface, it would be necessary to divide the sample using multiple cuts. Analysis of the chemical substation showed places with higher and lower amounts of completely melted and cooled mixed material from the copper wire electrode and the machined material. The content of the adhered copper on the surface varies based on location by 25 wt. %. Moreover, significant reduction of iron wt. % on the worked material was observed, even though the machined sample had 50 % of iron and 50 % of rhodium. The reason behind this is the difference in energy needed for evaporating the same amount of rhodium and iron. Rhodium requires twice as much energy to evaporate 10 mg of material than iron.

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