EVALUATION OF A TOTAL HEIGHT OF PROFILE OF THE SURFACE MACHINED BY WEDM

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Wire electrical discharge machining (WEDM) is a non-conventional machining technology, which has become indispensable in many industries. Typical morphology of a surface machined by wire spark erosion (WEDM) is characterized by plenty of craters caused by electrospark discharges produced during the cutting process. The study deals with the evaluation of the surface morphology using a 3D colour-filtered and unfiltered images. Attention was also paid to a total height profile of craters Rt. The experiment consisted of three different settings of machine parameters and 3 metallic materials were used for the testing.

KEYWORDS

WEDM, electrical discharge machining, steel X210Cr12, titanium alloy Ti-6Al-4V, aluminium Al 99.5, total height of profile

1 INTRODUCTION

Wire electrical discharge machining uses electrical impulses between two electrodes to divide materials [Jameson 2001]. WEDM is a widely used technology in machining of accurate and complicated parts. In addition to the material removal rates (MRR) and accuracy of machining, the surface quality is another important index for evaluation of machining performance. In the production of accurate parts, it is typical to require a very high surface quality without subsequent finishing operation, e.g. polishing. Therefore, it is necessary for efficient WEDM that the machined surface reached the desired quality, without additional polishing. There are many factors that have a major impact on the quality of machined surface and they can be found using different methods [Matousek 2009], [Matousek 2010], [Blecha 2011], [Blecha 2011].

[Hasçalyk 2004], [Robelo 1998] found that the roughness of WEDMed surfaces increased accompanying the increase of discharge energy, since greater discharge energy would produce larger craters, causing greater surface roughness on the workpiece. [Liao 2004] found that the most important factor that influences surface roughness is pulse duration. Therefore, the roughness could be decreased by reducing the discharge energy. [Scott 1991] used a factorial design method, to determine the optimal combination of control parameters in WEDM considering the measures of machining performance as metal removal rate and the surface finish. The study concludes that discharge current, the pulse duration and the pulse frequency are significant control factors. [Tarng 1995] used a neural network model to estimate cutting speed and surface finish using input settings as pulse duration, pulse interval, peak current, open circuit voltage, servo reference voltage, electric capacitance and table speed.

Although the machine setting parameters are a major factor, it is the material properties of the workpiece that define the resulting surface quality. Using WEDM technology, it is possible to machine very hard, tough, or, conversely, soft materials with only a single condition: their minimum electrical conductivity. Parameters of surface quality are influenced by the set of physical and mechanical characteristics of the machined material and the type of its heat treatment. Using the full potential of the final electrical discharge machining (cutting) process is very difficult due to a large number of possible varying parameters.

2 EXPERIMENTAL SETUP AND MATERIAL

2.1 *Experimental Material*

The samples for the experiment were made of pure aluminium Al 99.5, alloy cold-work tool steel X210Cr12 and titanium alloy Ti-6Al-4V.

Aluminium Al 99.5 is a material with low specific weight. Its undeniable advantages include excellent corrosion resistance, good weldability and suitability for anodizing with a hardness of 20 to 42 HBS, tensile strength 65-160 MPa and chemical composition according to Tab. 1. It is used in almost all sectors of industry to structural elements and low tension mechanical applications requiring material of high formability, highly corrosion resistant and very well thermally and electrically conductive. It is weldable by almost all methods. The initial semi product of steel rod with 20 mm in diameter, from which a prism was made by WEDM, was used for the experiment.

Contents	Si	Fe	Cu	Zn	Ti
Max (wt%)	0.3	0.4	0.05	0.07	0.05

Table 1. Chemical composition of aluminium Al 99.5 set by a standard.

The alloy cold-work tool steel X210Cr12 was heat treated in four different ways according to Tab. 2. This material is primarily used for highly stressed tools with high performance and durability for cutting and punching metallic materials of small thicknesses (up to 4 mm). Tools for cold forming, which are highly stressed and tools with simple shape and high wear resistance with lower requirements for toughness, e.g. moulding stamping dies, drawing dies, girders, dies, extrusion dies, push pins, profiled and threaded cylinders. The material belongs to the 9b machinability class, it is hardly formable and weldable. An initial semi product of prism of 15 mm thickness was used in the experiment.

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
Type of HT	Heat treatment (HT)					
1	780 °C/ 20 hours / cooling in furnace					
2	hardened and tempered 960 °C / 1 hour / oil 200 °C / 2 hours / air					
3	hardened 1100 °C / 1 hour / oil					
4	soft annealing 760 °C / 2 hours / furnace					

Table 2. Chemical composition of steel X210Cr12 set by a standard and heat treatment of the individual samples.

Titanium alloy Ti-6Al-4V with a chemical composition as shown in Tab. 3., was applied in two sets. The first set – the material without additional heat treatment, the second set – heat treatment, see Tab. 3. This alloy has a high tensile strength of 900 MPa and excellent resistance to corrosion. It has the highest ratio between strength and specific weight of all metallic materials. It has high biocompatibility and ability to withstand thermal loads at temperature up to 315 °C. It is used for manufacturing structural components of weapons and planes, turbine blades, fasteners, medical and dental implants and sport equipment. 18 mm thick prism as an initial semi product was used for the experiment.

Contents	Al	Fe	O	V
Min (wt. %)	5.5			3.5
Max (wt. %)	6.75	0.25	0.2	4.5
Type of HT	Heat treatment (HT)			
1	hardened and tempered 940 °C / 45' / water 500 °C / two hours / air			

Table 3. Chemical composition of titanium alloy Ti-6Al-4V set by standard and one type of heat treatment

2.2 Wire EDM Machine Setup

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. To determine the effects of parameters of gap voltage, pulse on (T_{on}) and off time (T_{off}), wire feed and discharge current to the machined surface, their different settings were used (Tab. 4.) for each of the three samples made from individual materials. The values of 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 4. Machining parameters used in the experiments

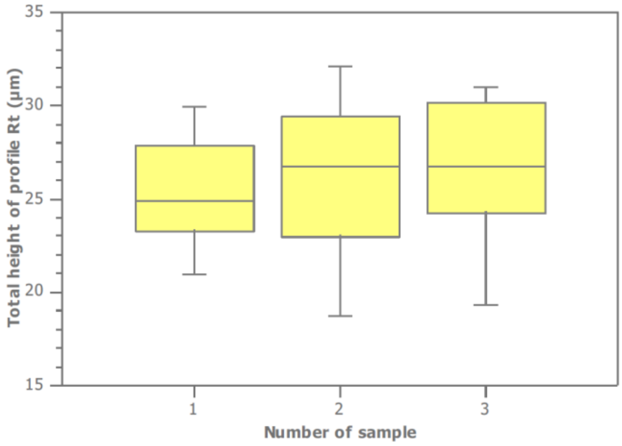
3 RESULTS OF EXPERIMENT

Machined surfaces of the samples were studied using light microscopy on 3D opto-digital microscope with high resolution OLYMPUS DSX 510. The surface relief was observed in the colour-filtered and unfiltered 3D images in which the value of the highest profile height Rt was marked. 10 images at random places on the surface were taken in each sample.

The profile parameter Rt is sensitive to changes in surface texture, since it is purely a height parameter and not a parameter based on the average value. The parameter Rt is suitable to use especially if it is not permissible to damage the opposite contact surface, or in the case of the sealing surface when insufficient fit with the opposite face may cause dysfunction of the connection [Gadelmawla 2002], [MacDonald 2002].

3.1 Results of the Aluminium Al 99.5 Surface Analysis

The surface of the samples made of aluminium Al 99.5 consists of a number of deep craters, the maximum total profile height Rt of which was measured for the sample 2, which is 32 µm. This surface is shown in the colour-filtered (Fig. 1.) and unfiltered image (Fig. 2.). The graph 1 shows that the sample 1 has the smallest scatter of the measured values and the sample 2 the largest, when the measured values were in the range from 18 to 32 µm. The average value of Rt for all samples was almost identical.



Graph 1. Total height of profile Rt of the samples made of Al 99.5

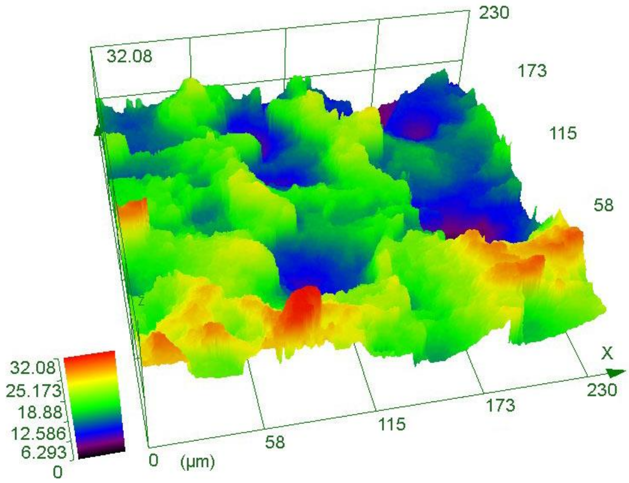


Figure 1. 3D picture of the sample 2 made of Al 99.5 magnified 1,200x, T_{on}=8 µs, T_{off}=55 µs, current=25 A

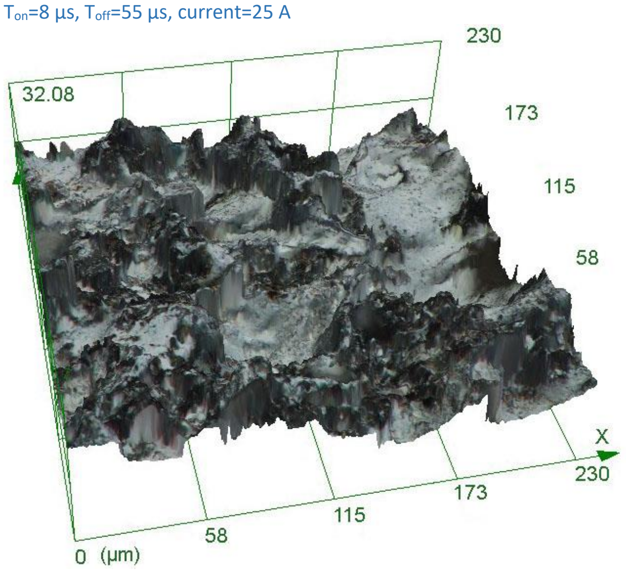
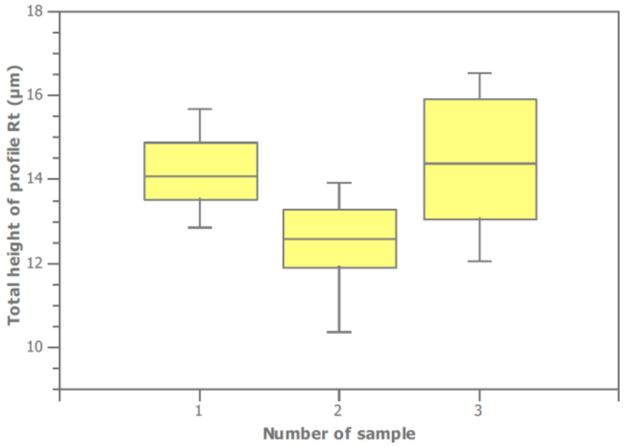


Figure 2. 3D picture of the sample 2 made of Al 99.5 magnified 1,200x, T_{on}=8 µs, T_{off}=55 µs, current=25 A

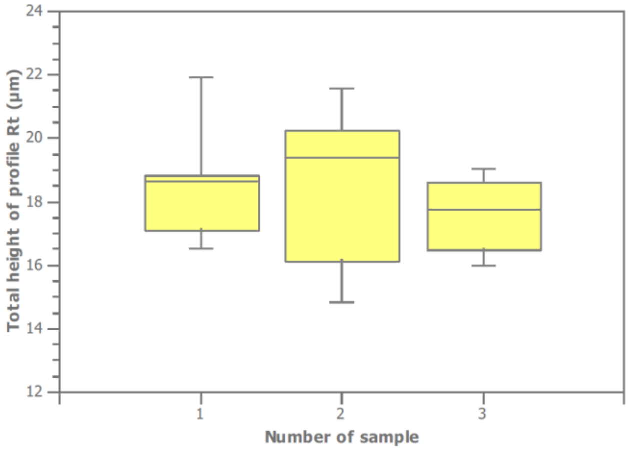
3.2 Results of the Steel X210Cr12 Surface Analysis

The measured values Rt for the samples made of high-chrome steel X210Cr12 with heat treatment 1 (780 °C / 20 hours / furnace) were put together into Graph 2. The lowest values were measured for the sample 2 and they were in the interval from 10 to 14 µm. This sample also had the lowest average value of Rt. The samples 1 and 3 have almost identical average values, but the sample 3 had the highest measured value of Rt of all the samples, 16 µm. The samples with the type of heat treatment 2 (hardened and tempered) have a maximum measured value of Rt 22 µm and a minimum of 15 µm, which is evident from Graph 3.



Graph 2. Total height of profile Rt of the samples made of steel X210Cr12 with the type of heat treatment 1

The sample 2 had the highest average value of Rt and the sample 3 the lowest value - 18 µm. The colour-filtered image of the sample 2 surface with the lowest value of Rt is on Fig. 3 and the unfiltered image in Fig. 4. The surface of this sample is covered only with shallow craters. There are no obvious smooth crater floors and the surface is very bumpy.



Graph 3. Total height of profile Rt of the samples made of steel X210Cr12 with the type of heat treatment 2

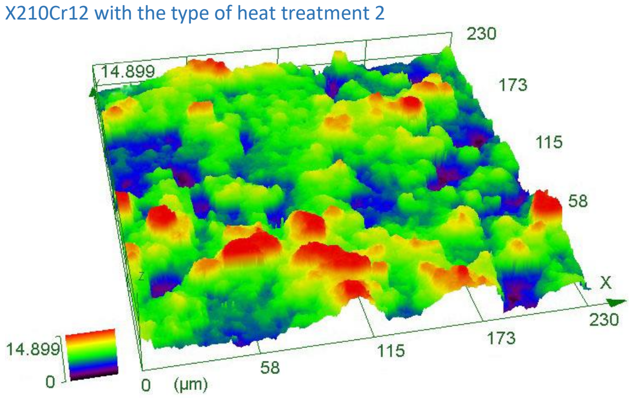


Figure 3. 3D picture of the sample 2 made of steel X210Cr12 with the heat treatment 2, magnified 1 200x, T_{on}=8 µs, T_{off}=55 µs, current=25 A

The total height of profile in the samples with heat treatment 3 was in the interval from 9 µm to 14 µm, which is evident from Graph 4. Sample 2 had the lowest average value of Rt, while the sample 3 had the highest value.

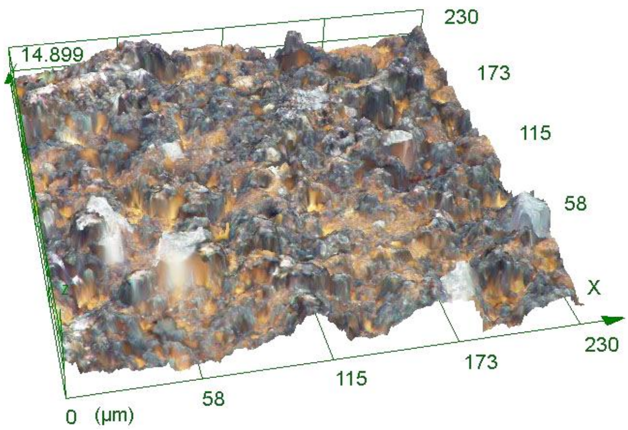
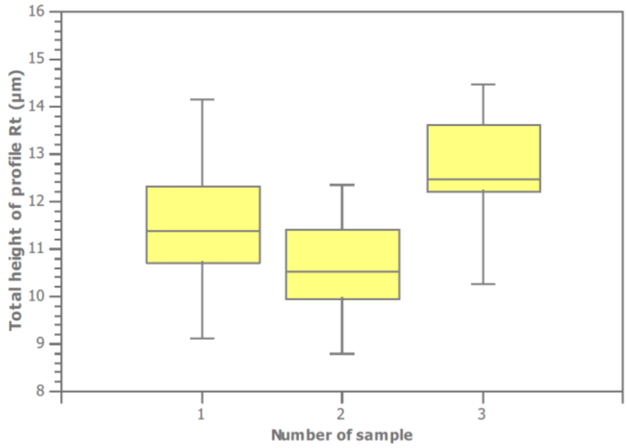
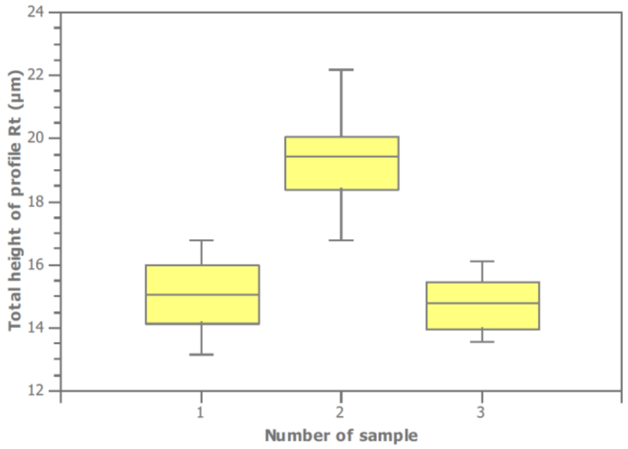


Figure 4. 3D picture of the sample 2 made of steel X210Cr12 with the heat treatment 2, magnified 1 200x, T_{on}=8 µs, T_{off}=55 µs, current=25 A



Graph 4. Total height of profile Rt of the samples made of steel X210Cr12 with the type of heat treatment 3

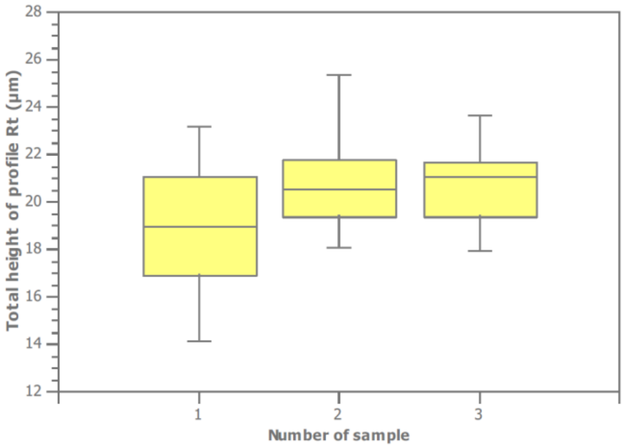
The measured values of Rt for the samples with heat treatment 4 were put together into Graph 5. The sample 2 had the highest total height of profile – 22 µm. The lowest value was measured for sample 1 – 13 µm.



Graph 5. Total height of profile Rt of the samples made of steel X210Cr12 with the type of heat treatment 4

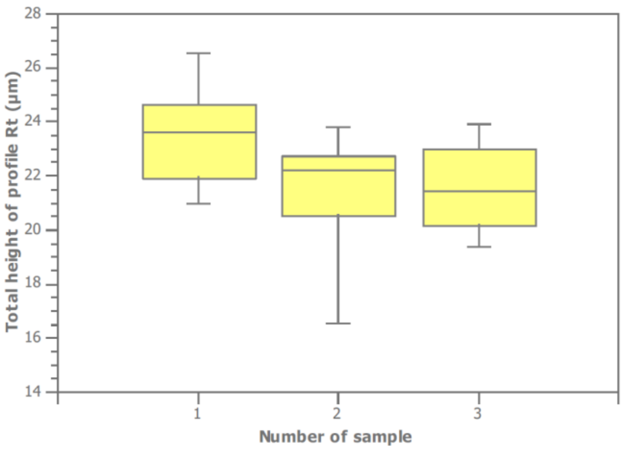
3.3 Results of the Titanium Alloy Ti-6Al-4V Surface Analysis

Total heights of profiles of the Rt samples made of titanium alloy Ti-6Al-4V without heat treatment were plotted to Graph 6. The sample 1 had the lowest measured value – 14 µm. This sample also had the lowest average value of Rt. The maximum total height of profile was measured in the sample of 2 – 25 µm.



Graph 6. Total height of profile Rt of the samples made of titanium alloy Ti-6Al-4V without heat treatment

The surface of the samples made of Ti-6Al-4V with a heat treatment is shown in the colour-filtered Fig. 5 and unfiltered Fig. 6. There are only a few higher projections on the surface and the rest is covered with shallow crater floors, which were formed during the erosion process. The Rt values measured on the samples of the heat-treated titanium alloy have been plotted in Graph 7. The maximum total height of profile was measured in the sample 1 – 27 µm. This sample also had the highest average value of Rt. The lowest value of Rt was measured in the sample 2, only 16 µm.



Graph 7. Total height of profile Rt of the samples made of titanium alloy Ti-6Al-4V with heat treatment

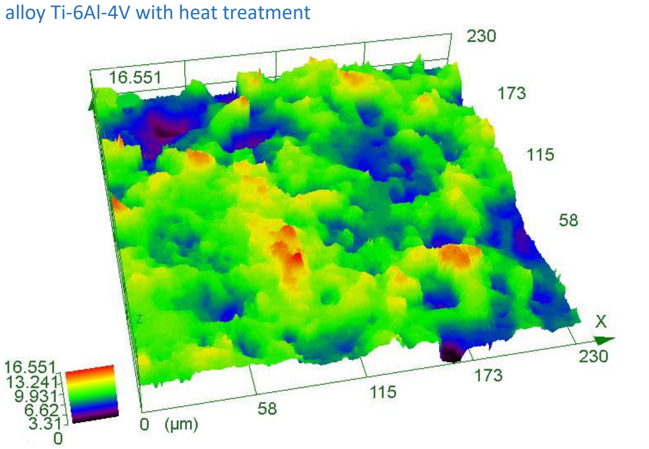


Figure 5. 3D picture of the sample 2 made of titanium alloy Ti-6Al-4V with heat treatment, magnified 1 200x, T_{on}=8 µs, T_{off}=55 µs, current=25 A

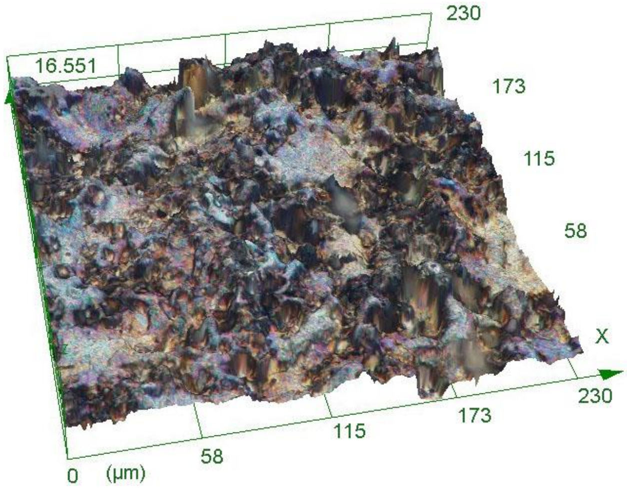
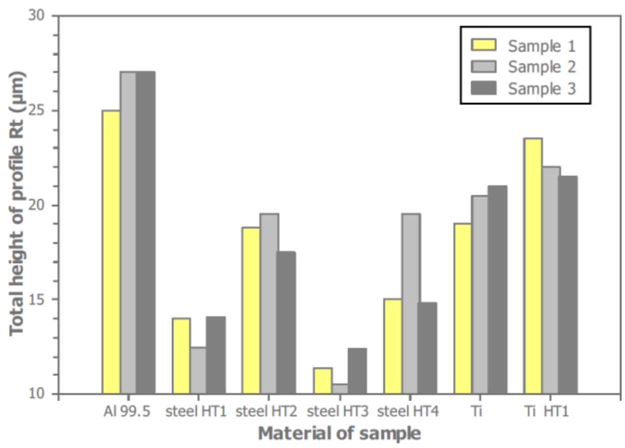


Figure 6. 3D picture of the sample 2 made of titanium alloy Ti-6Al-4V with heat treatment, magnified 1 200x, T_{on}=8 µs, T_{off}=55 µs, current=25 A

4 CONCLUSIONS AND DISCUSSION

The surface morphology in all samples consists of plenty of craters formed by the erosion process [Tosun 2003], [Han 2007]. The depth of the craters formed in this way is not only dependent on the setting parameters of the machine [Kumar 2013], [Kanlayasiri 2007], but also on the mechanical and physical properties of the machined material, which are a direct result of the microstructural parameters of the materials studied after individual heat treatments [Somashekhar 2010]. The measured average values of the total height of profile Rt in all samples were plotted into Graph 8.



Graph 8. Average value of Rt of the samples

The samples made of aluminium Al 99.5 had the highest values of Rt – 25 to 27 µm. The high Rt values are obviously associated with a low melting point of the material, low strength and relatively large grain size of the Al workpiece. In contrast, the samples made of alloyed tool steel X210Cr12 with heat treatment 3 (hardened) had the lowest average value of the total height of profile Rt - only 9–15 µm. This fact was undoubtedly supported by a higher melting point of the machined material, high strength, high level of internal stress after heat treatment and very fine-grained microstructure formed by tetragonal martensite. It is clear from Graph 8 that an identical material, after heat treatments, which are characterized by a lower strength and larger grain size of the individual phases constituting the material microstructure, show far higher Rt values compared to the material after hardening. The samples made of titanium alloy Ti-6Al-4V without heat treatment had a lower average value of Rt than the samples with heat treatment (hardened and tempered). This fact is entirely consistent with coarser microstructure of the titanium sample after heat treatment. The most noticeable difference in the average Rt values was observed in the sample 2 made of alloyed tool steel X210Cr12 with heat treatment 4 (soft annealing), when the value of Rt was 25 % higher than in the samples 1 and 3 of the same material with setting parameters on T_{on}=8 µs, T_{off}=55 µs, current=25 A. For the other samples of the various materials that were the subject of the experiment, the difference of average Rt value between them was less than 5 %.

The above experiments clearly show that the resulting surface roughness parameter Rt very strongly depends not only on the chemical composition of the machined material, setting parameters during the cutting process, but in particular on the mechanical parameters of the machined material. The mechanical properties of the materials are unambiguously given by basic microstructural parameters after a specific heat treatment of the material.

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