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Analysis of the surface quality of steel and ceramic materials machined by micro-EDM

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Abstract

This work deals with the execution of micro-slots on two different materials using μ-EDM milling. The experiments were carried out by varying machining approaches, which are strictly related to the surface quality. For both materials, tungsten carbide solid electrodes were used. The investigation focused on the different results obtained in terms of surface roughness and some others amplitude parameters to evaluate the different finishing level of the surface and to describe the different characteristics of these different families of materials. The aim is the identification of the surface characteristics of micro-slots executed according to UNI EN ISO 25178:2017. The results of this analysis can provide important information when designing micro-EDM milling processes.

Keywords: micro-EDM milling, surface finishing, UNI EN ISO 25178, AISI 316L, ZrC+10MoSi$_2$

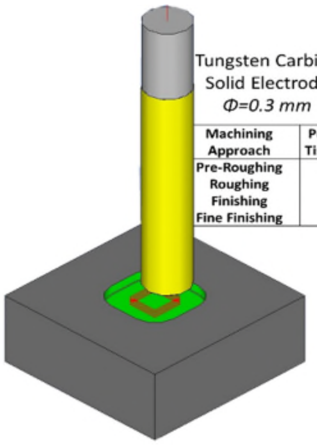
1. Introduction

Micro Electrical Discharge Machining (μ-EDM) is a non-conventional technology based on electrical discharges generated in the gap between the electrode and the workpiece. The sparks generated during the machining produce heat that melts and vaporises the workpiece material; part of the material resolidifies on the machined surface getting worse surface quality and, from the operational point of view, the operating life of the part could be compromised [1, 2]. All surfaces have a different texture depending on peaks and valleys, which vary in height and spacing and have properties related to the manufacturing strategy [3, 4]. Criteria and parameters for a full description of the surface texture are specified in international standard UNI EN ISO 25178:2017 [5].

Aim of the present paper is the characterization of the machined surface of micro-slots executed on two different materials (stainless steel and advanced ceramic material) machined by μ-EDM milling. The choice of these materials is due to the possibility of drawing a comparison between a well-known material and an innovative one. In particular, the selected ceramic is classified as an Ultra-High-Temperature Ceramics (UHTCs), a class of promising materials typically applied in extreme chemical and thermal environments thanks to their high melting point, good ablation resistance, excellent hardness and strength at elevated temperatures. UHTCs are conductive materials, so they are suitable to be processed by EDM process but, machinability problems can occur due to their high porosity level. Then, additives have been added to improve final density through the formation of small amounts of the liquid phase [6].

2. Experimental set-up

Experimental tests based on the execution of square micro-slots (0.5x0.5 mm) were carried out using μ-EDM machine Sarix SX-200, taking into account two workpiece materials: stainless steel (AISI 316L) and UHTC (ZrC+10MoSi$_2$). The experimental campaign was carried out varying the machining approach, which identifies the pulse type applied to the process (Figure 1) and consequently, the different finishing level of the machined surface. Hydrocarbon oil was used as the dielectric fluid.



Machining Approach	Pulse on Time [μs]	Frequency [kHz]	Peak Current [Index]	Voltage [V]
Pre-Roughing	6.6	90	80	150
Roughing	5	130	50	130
Finishing	5	140	100	100
Fine Finishing	2	180	100	90

Figure 1. Detail of micro-slot and process parameters.

3. Criteria for the evaluation of the machined surfaces

A 3D reconstruction of the micro-slots is performed by means of an autofocus laser probe equipment Mitaka PF-60. The physical principle of measurement is the autofocus variation along Z axis with a resolution of 1 nm and a magnification of 100X. After the areal scan, the raw data are extracted and elaborated with a software, developed by the authors, able to level the surface, eliminate the form factor (waviness), reconstruct the surface by means of a tassellation algorithm, calculate the amplitude parameters and save this surface in .stl format for successive study of the deviation of meshes with respect to a reference plane.

For the evaluation of surface texture, some amplitude parameters (Sa, Sq, Ssk, Sku, Sz) are evaluated by the equations defined by the standard UNI EN ISO 25178. Average roughness (Sa) describes in a general way the height variations, but it does not give information about the wavelength and it is no sensitive to small changes in the profile. For this reason, the evaluation of the surface texture is performed considering also the root mean square roughness (Sq) for an evaluation from a statistical point of view and further amplitude parameters such as skewness (Ssk), kurtosis (Sku) and the ten-point average of the absolute heights (Sz).

4. Results and discussion

The reconstructed surfaces show, for both materials, shallow craters and smooth surface irregularities for the finishing and fine-finishing approaches. Whereas for pre-rough and rough machining, the craters are deeper and surface irregularities are most apparent. In particular, craters are well-defined on a stainless steel machined surfaces (Figure 2). The deviation of meshes shows several working witnesses on the ceramic surface and the electrode trace on both materials, in particular for the fine-finishing approach. The Sa trends as a function of the machining approach are similar for both materials, even if the values obtained for AISI 316L are always lower than those obtained for ceramic.

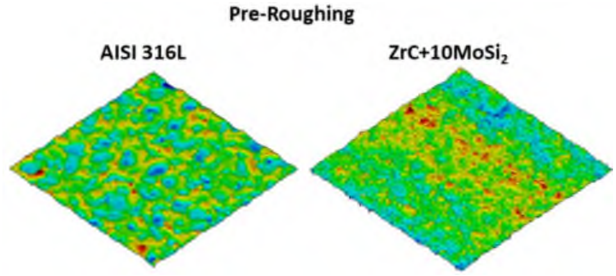


Figure 2. Example of surface 3D reconstruction and deviation of meshes.

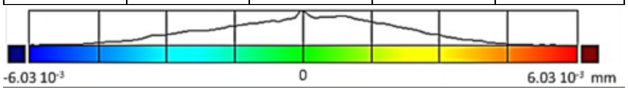
Figure 3 and Figure 4 report histograms about the height distribution of z(x,y) and the estimated values of Sa, Sq, Sku, Ssk and Sz for the machined surfaces. Histograms represent normal distribution with a confidence interval equal to 99.73% (±3σ).

For AISI 316L surfaces, results show that the bulk of the material of the sample is above the mean line presenting few deep valleys. On the contrary, for ceramic surfaces, the bulk of the material is below the mean line presenting few high peaks. From the Sku point of view, the machined surfaces look like spiky and the profile distributions are closed to their average values. Even though similar trends can be observed for ceramic and steel. The differences in Ssk and Sku values denotate dissimilar characteristics between the two materials explained by the different material structures and the presence of voids (caused by the sintering process) for the ceramic material. The different texture is represented also by Sz, in fact, it is directly related to the finishing level of the machining. In particular, it is lower for fine-finishing approaches and, in all cases, it shows minor differences between peaks and valleys for AISI 316L.

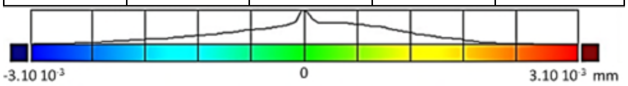
5. Conclusions

In the present paper, differences in machined surface characteristics when working two completely different family of materials are outlined as a function of the machining approach. These differences are not limited to the calculus of Sa but also consider other amplitude parameters, as suggested by UNI EN ISO 25178, giving a complete analysis of the surface finishing information about peaks and valleys shapes and distribution with respect to the mean line. The results of this investigation must be carefully considered in relation to the final application of the manufactured part. The materials selected are different in terms of structure, mechanical and physical properties; for these reasons, the estimated surface roughness parameters show different behaviours. In particular, AISI 316L machined surfaces are characterized by few irregularities, less working witnesses and well-defined craters, which dimensions are related to the machining approach. These aspects are confirmed also by the negative values of Ssk that describe a plateau-like surface.

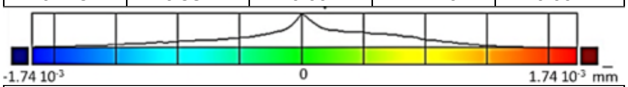
Pre-Rough				
Sa	Sq	Ssk	Sku	Sz
1.608	2.009	-0.211	3.061	0.021



Rough				
Sa	Sq	Ssk	Sku	Sz
0.799	1.028	-0.492	3.760	0.013



Finish				
Sa	Sq	Ssk	Sku	Sz
0.445	0.587	-0.602	4.470	0.007



Fine-Finish				
Sa	Sq	Ssk	Sku	Sz
0.266	0.343	-0.090	3.830	0.007

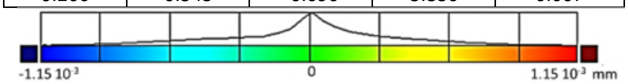
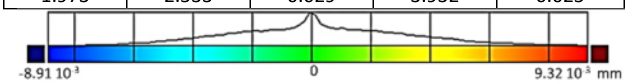
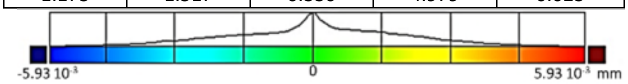


Figure 3. Roughness parameters and distribution for AISI 316L.

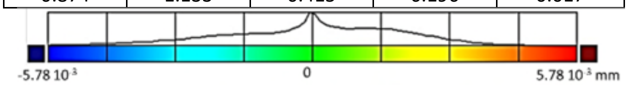
Pre-Rough				
Sa	Sq	Ssk	Sku	Sz
1.973	2.533	0.029	3.932	0.025



Rough				
Sa	Sq	Ssk	Sku	Sz
1.173	1.517	0.330	4.979	0.023



Finish				
Sa	Sq	Ssk	Sku	Sz
0.874	1.133	0.415	6.196	0.017



Fine-Finish				
Sa	Sq	Ssk	Sku	Sz
0.684	0.844	0.201	3.062	0.011

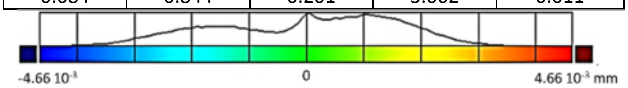


Figure 4. Roughness parameters and distribution for $ZrC+MoSi_2$.

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