2D AND 3D SURFACE ROUGHNESS PARAMETERS OF SURFACES MACHINED BY EDM

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Abstract
In electro discharge machining (EDM or spark erosion) the roughness of the machined surface plays a very important role in the applicability of the process. The EDM machined surfaces are near isotropic, so the 3D measured surface roughness parameters can be compared to the parameters measured by 2D method. This paper reports on the results of research on the comparison of 2D and 3D surface roughness parameters of EDM machined surfaces of tool steels. Based on the results of the performed cutting experiments and the subsequent measurements, conclusions will be drawn regarding the connection between the 2D and 3D surface parameters and the extent of roughness of steel surfaces machined by two type electrode material.

Keywords: *EDM, surface roughness, 3D roughness measurement*

1. Introduction

Electro erosion machining is used more and more widely for the machining of hard-to-machine, modern materials, often as final machining. This is why the examination of the microgeometry of the machined surface is important. In the literature, several people have already dealt with the roughness of EDM surfaces as a function of technological data (Puertas et al., 2004; Lee et al., 2001; Papazoglou et al., 2020). The 2D surface roughness parameters commonly used in EDM include the arithmetic average roughness (R_a) (Hess et al., 2024; Sahay et al., 2018). Nowadays, researchers prioritize the examination of 3D roughness parameters, primarily examining their dependence on technological data (Dudek et al., 2018). The 3D surface roughness parameters are important for solving contact surface mechanics problems and are estimated from the well-known 2D profile parameters using the cross-section method for the calculation of mean values of roughness height, spacing, and shape (Rudzitis et al., 2014). The EDM surface is made up of overlapping, irregularly located craters (Figure 1), the formation of which is influenced by several technological parameters - e.g. voltage, current strength, cycle (pulse) time – affects.

Figure 1. *Microstructure of EDM machined surface*

EDM surface looks homogeneous, has a silky, dull sheen. The energy content of the discharges can be controlled by changing the electrical parameters. Among the electrical parameters, current strength and pulse time have the greatest effect on surface roughness. However, these parameters cannot be set on modern machining machines, they are chosen by the machine itself depending on the specified VDI grade.

When using today's modern EDM machine tools, technological parameters are automatically generated by the machine based on the VDI grade. VDI stands for German Engineering Association (Verein Deutscher Ingenieure). The VDI 3400 standard deals with EDM. This recommendation groups machined surfaces into so-called VDI grades based on surface roughness from VDI 00 to VDI 45. Presently, the VDI scale is used worldwide in the tooling industry. The parameter is a surface roughness characteristic and complements and replaces the general surface roughness metrics (Maros et al., 2023).

The roughness of surfaces machined by EDM can therefore be said to be isotropic, because there are no distinct directions in terms of changes in surface roughness. For these surfaces, it makes sense to compare the 2D along the line and the 3D roughness parameters along the area. In this article, we examine how the main 2D and 3D roughness parameters change during EDM by changing the VDI grade. The change of the roughness parameters was investigated as a function of the VDI grade of the machining. Similar studies have been reported in (Mikó et al., 2014).

2. Experimental conditions

For the experiment, two types of tool steel were used. These materials usually applied for plastic injection moulding tools The test pieces were machined by electro discharge machining. The chemical composition of the steels is shown in Table 1.

Table 1. *Chemical composition of plastic forming tool steels used for experiments*

Material	**C, %**	**Si, %**	**Mn, %**	**Cr, %**	**Mo, %**	**Ni, %**	**S %**
C45U (1.1730)	0.45	0.30	0,70				
40CrMnMoS8-6 (1.2312)	0.40	0.40	1.50	1.90	0.20		0.08

The test pieces were 100x120x20 mm, rectangular cross-section, non-heat-treated plates, the surface of which was pre-ground for more efficient sparking. 5 mm deep cavities were made on these test pieces by EDM (Figure 2). Sinkings were performed on a test piece in 5 different VDI grades with two electrodes. There were tested 5 different VDI grades on one specimen with two types of electrodes. On one test piece 5 different VDI grades were tested with two types of electrodes. The VDI grades set were 18, 21, 25, 29, 36.

Figure 2. *Test piece machined with EDM*

To carry out the machining experiments, copper (red copper - see Figure 3.) and graphite electrodes were used for all test piece materials. The type of copper electrodes used was CuETP electrolytic copper and graphite of type ELOR-50-F, with a cross section of 55 x 15 mm.

Figure 3. *Copper electrode used for cutting experiments*

The machining experiments were carried out on a Neuar CNC-C50 type electro discharge machine. During the machining the dielectric used was petroleum.

The surface roughness measurements of the machined cavities were carried out in the laboratory of the Institute of Manufacturing Science of the University of Miskolc, using an AltiSurf 520 three-dimensional surface topography machine. 2D profile and 3D spatial roughness parameters were measured as well for the comparation.

3. Experimental results

From the results of the EDM experiments, we can draw conclusions on both the effect of the set VDI grade on the profile roughness and on the connection between the 2D and 3D surface roughness parameters when machining two type of tool steels using copper and graphite electrodes.

Figure 4 shows the variation of the average the 2D (R_a) and 3D (S_a) surface roughness parameter as a function of VDI grade for the tool materials tested, in the case of copper electrodes.

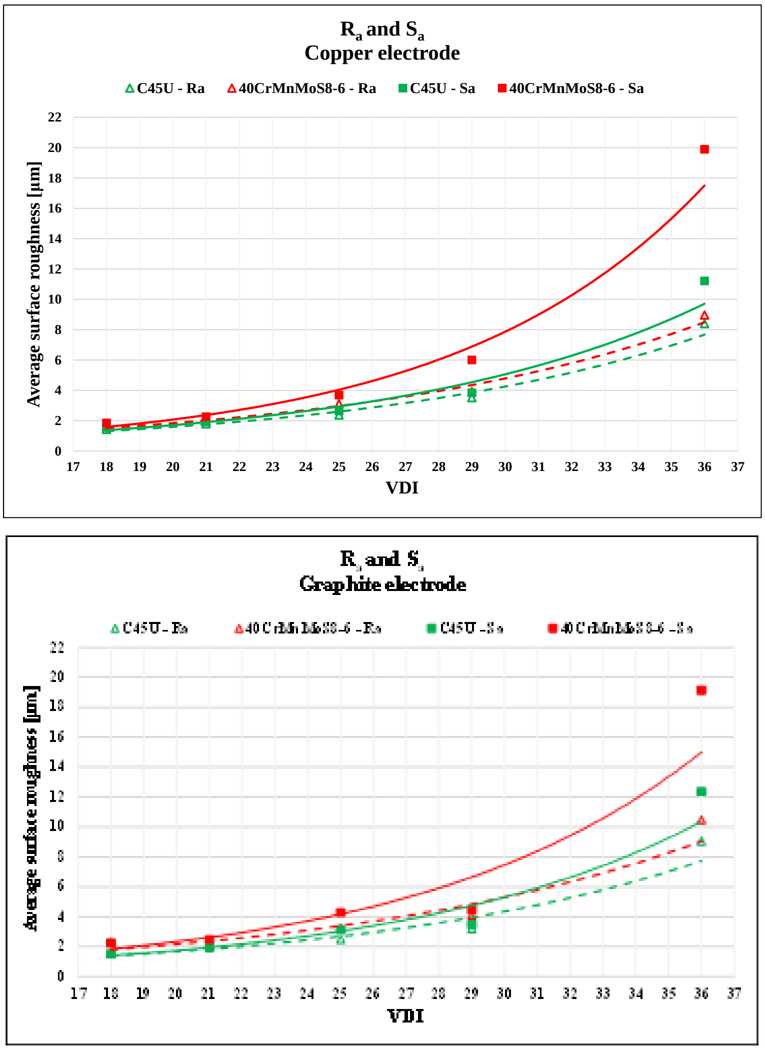
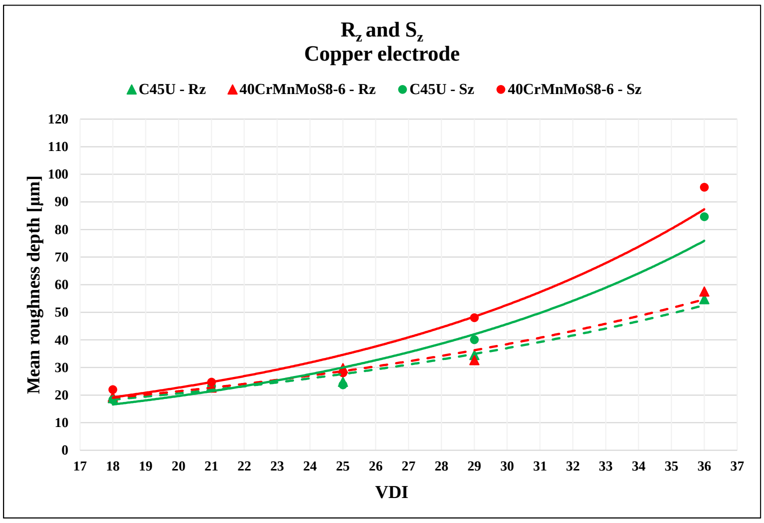


Figure 4. *2D and 3D average surface roughness of EDM machined tool steels as function of VDI grade*

It can be seen from Figure 4 that average roughness of C45U material is always smaller than that of tool steel 40CrMnMoS8. The roughness of the surfaces produced varied between R_a = 1.4-11 µm and S_a = 2-20 µm. The average (or mean) roughness of surfaces machined with a graphite electrode is slightly higher than those machined with a copper electrode. The values of the spatial roughness are in all cases higher than the values measured on the profile - this is especially true in the case of higher average roughness. The value of the S_a parameter can be up to 1.5-2 times the R_a value.

Figure 5 describes the variation of the mean roughness depth (R_z, S_z) as a function of VDI grades.



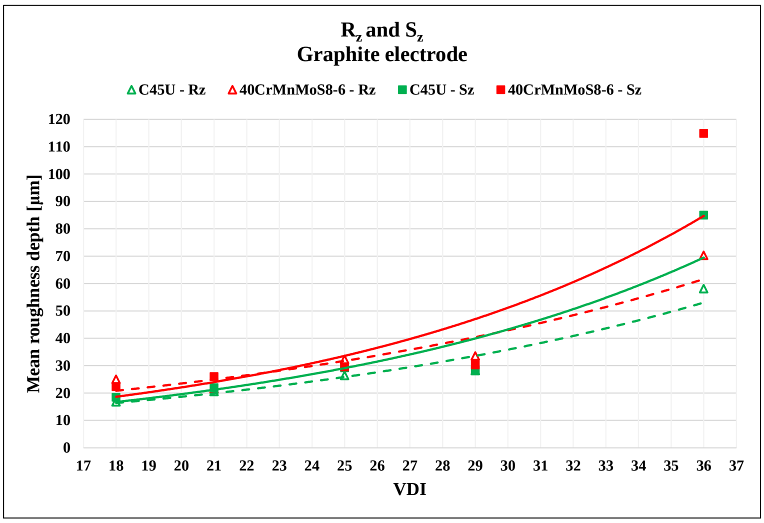


Figure 5. *2D and 3D mean roughness depth of EDM machined tool steels as function of VDI grade*

Based on Figure 4, it can be said that the trends are like what was said about the average roughness. In terms of material quality, here too, the C45U quality has a lower roughness. The 3D roughness values here are also higher than the profile roughness values. The mean roughness depth parameter R_z and S_z change analogously to the R_a, S_a parameter depending on the VDI grade. R_z values ranged from 15.8 to 70.3 µm and for S_z 20-70 µm. The values of R_z compared to R_a vary in the ratio $R_z \approx (6 \div 10) \cdot R_a$. This ratio is usually estimated by the manuals as $R_z \approx 8R_a$. For Sa roughness this value is about $S_z \approx (4 \div 9) \cdot S_a$.

Figure 6. shows the change of the material ratio surface roughness parameters (R_{mr}, S_{mr}) as function of VDI grade. The material ratio parameters R_{mr}, S_{mr} are used to characterise the functional and wear properties of surfaces. The higher the percentage R_{mr} and S_{mr} values of a given surface, the more

favourable its functional properties. When measuring the material ratio, the values of the material fraction parameter were determined at a depth of 10 μm.

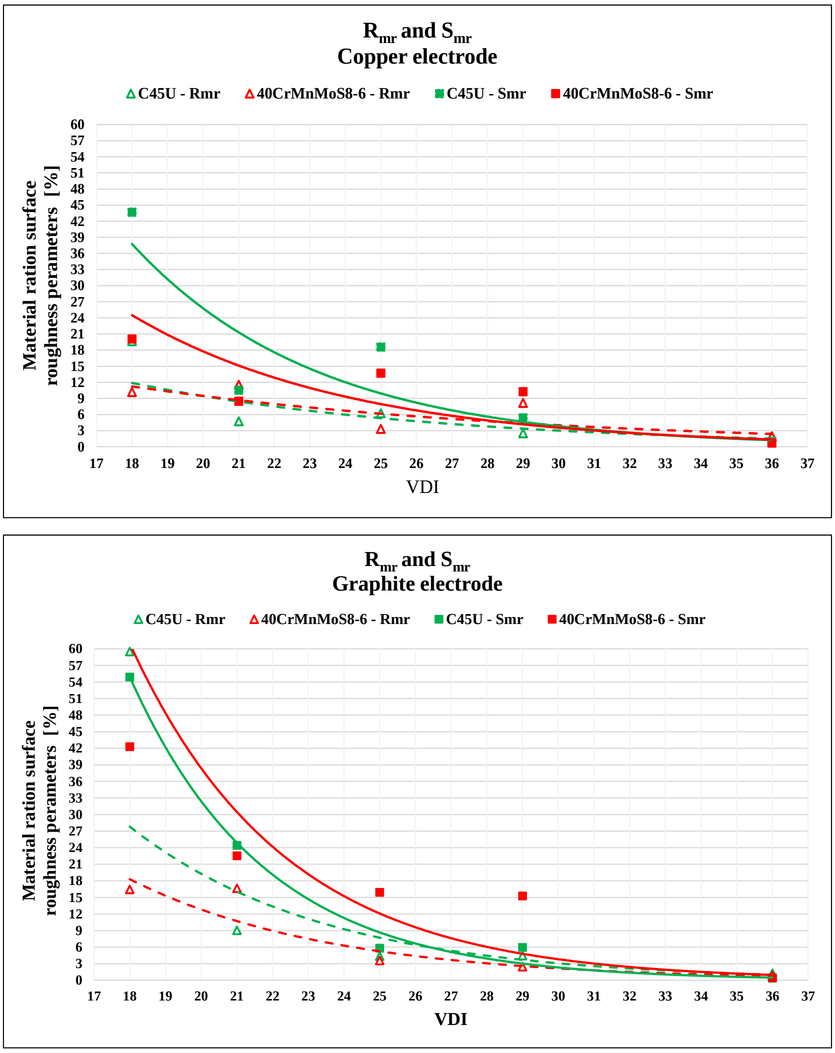


Figure 6. *2D and 3D material ration surface roughness parameters of EDM machined tool steels as function of VDI grade*

On Figure 6 it can be observed that the best material ratio values are achieved at VDI 18, at the smallest VDI grade. With increasing VDI grades, regardless of tool and workpiece material, the surface properties deteriorate and the material ratio parameter difference between steels decreases. At C45U material quality, we always obtained more favourable material ratio parameter values than at 40CrMnMoS8 material quality. It is also interesting to observe that the spatial values (S_{mr}) are typically larger than the profile parameters (R_{mr}). This is interesting because, based on this phenomenon, the spatial parameters show a preferable surface, then the 2D measured parameters. It can also be observed that when machining with a graphite electrode, more favourable (larger) material ratio parameter values are obtained.

4. Conclusions

Summarising the results of the research work on 2D and 3D surface roughness parameters of tool steels machined by EDM, the following conclusions can be drawn:

- By increasing the VDI grade, the spatial and linear roughness parameters both deteriorate, that is, the amplitude parameters increase, the material ratio parameter decreases.
- Regarding the amplitude roughness parameters (R_a, R_z and S_a, S_z), values of 2D parameters are always smaller than that of the 3D.
- Regarding the material ratio parameter, the spatial roughness parameters are also the largest, which is interesting because from an operational point of view, larger values for this parameter are more favourable.
- Regarding the two types of electrode materials, it can be said that the roughness amplitude parameters are greater at graphite electrode then at copper. At the same time, the parameter values of the material ratio are more favourable in the case of the graphite electrode.
- In the case of EDM surfaces, the mean roughness depth R_z, S_z varied analogously to the average roughness R_a, S_a. Based on the measurement results, the relation $R_z \approx (6 \div 10) \cdot R_a$ and $S_z \approx (4 \div 9) \cdot S_a$.
- According to the material ratio parameters (R_{mr}, S_{mr}) determined at a depth of 10 μm, the best operating and wear properties are achieved at VDI grade 18, which continuously deteriorate as the grade increases, and the results obtained on each tool target show a decreasing difference with increasing grades.
- Among the two machined tool steels, the less alloyed C45U material quality shows more favourable surface roughness values than 40CrMnMoS8, for all examined roughness parameters.

The roughness of the surfaces machined by EDM is isotropic, therefore conclusions can be drawn about the relationship between the 2D and 3D roughness parameters. Summarizing our research work, we can say that the surface roughness parameters deteriorate as the VDI grades increase (R_a, R_z, S_a, S_z increases, R_{mr}, S_{mr} decreases) Spatial and linear parameters are not the same size. In all cases, the spatial values are larger. But while this means a less favourable surface quality for the amplitude parameters, it means a better surface quality for the material ratio parameters. In order to further analyse the relationship between the two types of parameters, we intend to carry out further investigations involving other roughness parameters.

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