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INVESTIGATION OF ELECTRO DISCHARGE MACHINING OF TOOL STEELS BASED ON THE ROUGHNESS OF THE MACHINED SURFACES

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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. This paper deals with a comparative study of the electro discharge machining of tool steels based on the roughness characteristics of the machined surfaces. Another aim of the research is to investigate which tool materials (electrode material, copper, or graphite) are most effective to achieve the best possible surface microgeometry. Based on the data of the performed cutting experiments and the subsequent measurements, conclusions will be drawn regarding the machinability of the tested tool steels and the applicability of the electrode materials used.*
Keywords: *electrical discharge machining; copper, graphite electrodes; functional roughness parameters.*

1. INTRODUCTION

Thanks to the development of the materials to be machined, industry has started to work with materials of increasing hardness and strength, which would be extremely difficult or impossible to machine with traditional methods. This has led to the development of various non-traditional machining processes, one of the most important of which is electro discharge machining or spark erosion [1]. This process, which is suitable for machining electrically conductive, high hardness materials, allows the formation of spatial surfaces. Its popular field of application is the production of injection moulding tools.

Several papers deal with the examination of different tool materials, including copper, bronze and graphite electrodes [2, 3, 4]. Paper [5] presents a comparison of graphite and copper electrodes to analyse the efficiency of material removal. In present article, we investigate the machinability of different tool steels used for injection moulding machined with copper and graphite electrodes of plastic parts, based on the roughness of the machined surfaces. In the literature, several people have already dealt with the roughness of EDM surfaces as a function of technological data [6, 7, 8, 9]. In this paper, we present our research results obtained during the examination of the microgeometric characteristics of EDM machined surfaces with copper and graphite electrodes.

The EDM surface is made up of overlapping, irregularly spaced craters (Fig. 1), the formation of which is influenced by a number of process parameters such as voltage, current, cycle time [1].

When using today's modern machine tools, most of these parameters are automatically generated by the machine tool and set to optimal values for processing. On EDM equipment, the optimization is based on the VDI grade, which is set by the machine operator before the start of machining. VDI stands for German Engineering Association (Verein Deutscher Ingenieure). This organization develops standard technical recommendations to help solve various technical processes and problems. 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. The purpose of this is to standardize the surface characteristics of the parts, which is an essential aspect for engineers to design injection mould inserts produced by EDM. Today, 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.

The change of the roughness parameters was investigated as a function of the VDI grade of the machining. Similar studies have been reported in [10]. The implementation of the experiments and our measurement results are described below.

2. MICROSTRUCTURE OF THE EDM MACHINED SURFACE

The nature of EDM machined surface is different from that of a conventional machined surface. There is no directionality or groove corresponding to the federate. The machined surface is cratered. The roughness of the surface is created by the interaction of overlapping craters (Fig. 1). The dimensions of the craters depend on the characteristics of the spark discharge, the workpiece and electrode material.

Figure 1 Microstructure of EDM machined surface

In the case of long-duration, low-energy discharges, wide and shallow craters are created because the discharge channel widens. Such a surface is shiny in spots. High-energy discharges of short duration create deep craters because there is not enough time to dissipate the generated heat. Such a 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.

The roughness of EDM surfaces is now often only characterized by the VDI grade. At the same time, other roughness parameters are often also important from the point of view of operation. That is why it is important to choose the right roughness metrics. In our research, we examined the amplitude and material ratio parameters.

3. EXPERIMENTAL CONDITIONS

3.1 Machined materials and test pieces

During the experiment, the surfaces of four types of tool steel used for plastic injection moulding tools 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

Material	**C, %**	**Si, %**	**Mn,%**	**Cr, %**	**Mo, %**	**Ni, %**	**S %**
C45U (1.1730)	0.45	0.30	0,70				
40CrMnMo7 (1.2311)	0.40	0.30	1.50	1.90	0.20		
40CrMnMoS8-6 (1.2312)	0.40	0.40	1.50	1.90	0.20		0.08
45NiCrMo16 (1.2767)	0.48	0.23	0.40	1.30	0.25	4.00	

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). On one test specimen was tested at 5 different VDI grades with both copper and graphite electrodes. The VDI grades set were 18, 21, 25, 29, 36.

Figure 2 – Test piece machined with EDM

3.2 Electrodes

To carry out the machining experiments, copper (red copper) 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.

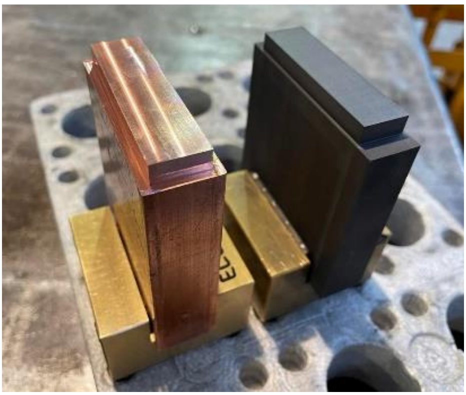

Figure 3 – Copper and graphite electrodes used for the experiments

3.3 Machine tools and measuring equipment

The machining experiments were carried out on a Neuar CNC-C50 type electro discharge machine. During the machining, the test pieces were clamped in a vice and 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. During this, we also measured the profile and spatial roughness parameters. In this article, we deal with the examination of profile parameters.

4. EVALUATION OF EXPERIMENTAL RESULTS

From the results of the EDM experiments, we can draw conclusions on the effect of the set VDI grade on the profile roughness parameters of the machined surface and the machining efficiency when machining different tool steels using copper and graphite electrodes.

4.1. Profile (2D), amplitude surface roughness parameter analysis

Figures 4 and 5 show the variation of the average surface roughness parameter R_a as a function of VDI grade for the tool materials tested, in the case of copper and graphite electrodes.

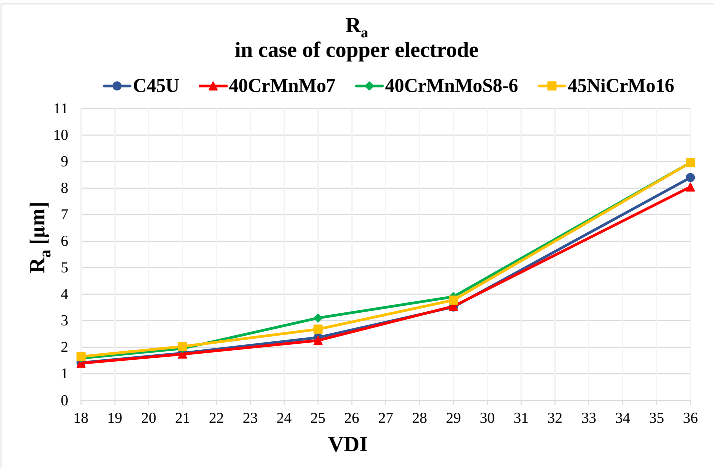

Figure 4 – Variation of R_a parameter as a function of VDI grade for copper electrode

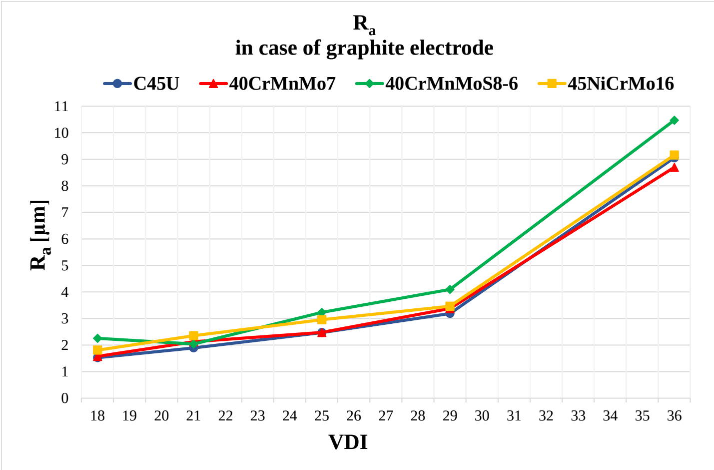

Figure 5 – Variation of R_a parameter as a function of VDI grade for graphite electrode

Figures 4 and 5 show that there is no significant difference in R_a between the different machined material grades. For both electrode materials, the lowest roughness values were obtained on the unalloyed C45U material grade and the worst roughness values were obtained on the 40CrMnMoS8-6 steel. The roughness of the surfaces produced with the copper electrode varied between R_a = 1.4-9 µm and with the graphite electrode between R_a = 1.5-10.5 µm, i.e. the two electrode materials also do not show significant values, although the roughness of the surfaces produced with the graphite electrode is mostly higher than that of the surfaces produced with the copper electrode.

Figures 6 and 7 describe the variation of the mean roughness depth R_z as a function of VDI grades. The general observations made for the R_a parameter are also valid here. The general statements made for the R_a parameter are also valid here. There are minor differences between the workpiece materials here as well, the mean roughness depth parameter R_z changes analogously to the R_a parameter depending on the VDI grade. For copper electrodes, R_z values ranged from 15.8 to 62.6 µm and for graphite from 16.7 to 70.3 µm. The values of R_z compared to R_a vary in the ratio $R_z \approx (6\div13)\cdot R_a$. This ratio is usually estimated by the manuals as $R_z \approx 8R_a$.

Figure 6 – Variation of parameter R_z as a function of VDI for copper electrode
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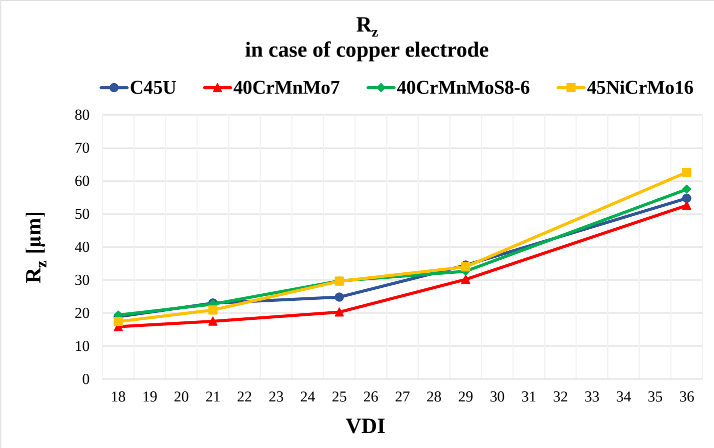

Figure 6 – Variation of parameter R_z as a function of VDI for copper electrode

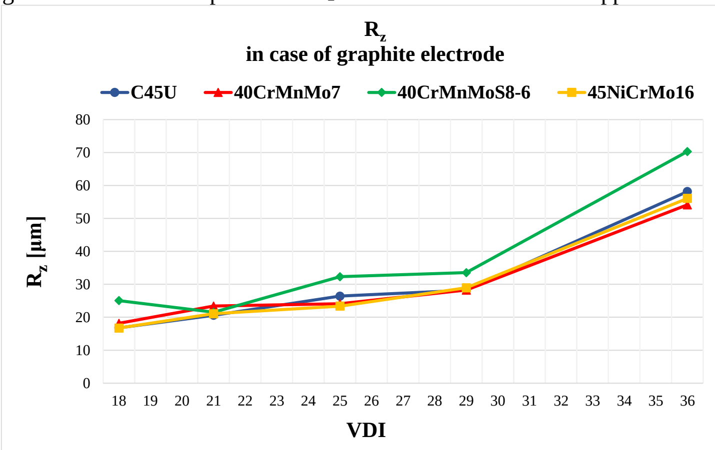

Figure 7 – Variation of parameter R_z as a function of VDI grade for graphite electrodes

Among the functional roughness parameters, the variation of the so-called material ratio parameter (R_{mr}) was investigated. The material ratio parameter R_{mr} is used to characterise the functional and wear properties of surfaces. The higher the percentage R_{mr} value of a given surface, the more favourable its functional properties. In our tests, the values of the material fraction parameter were determined at a depth of c = 10 µm. Figures 8 and 9 show the change in the material ratio parameters of surfaces made with copper and graphite electrodes in each VDI grade.

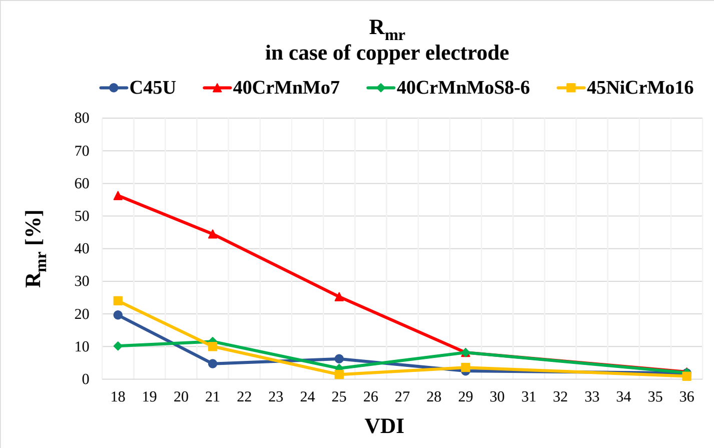

Figure 8 – Variation of R_{mr} parameter as a function of VDI grade for copper electrode

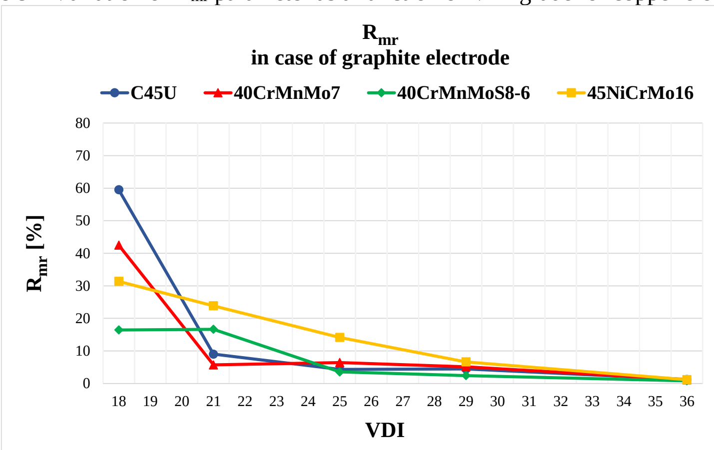

Figure 9 – Variation of R_{mr} parameter as a function of VDI grade for graphite electrode

In Figures 8 and 9, it can be observed that the best material ratio values are achieved at VDI 18 and that with increasing VDI grades, regardless of tool and workpiece material, the surface properties deteriorate and the material ratio parameter difference between steels decreases. In the case of copper electrodes, outstanding performance characteristics can be achieved when machining 40CrMnMo7 and, in the case of graphite, the same can be said for C45U and 45NiCrMo16.

4.1. Examination of machining times

We can draw conclusions about the productivity of the EDM process, i.e. the machining performance, from the machining time of each cavity. During the experiments, cavities with a cross-section of 55x15 mm and a depth of 5 mm were made by block EDM. Figures 10 and 11 show the machining time of the cavities made on the four types of tested tool steel workpieces as a function of the VDI degrees, in the case of copper and graphite electrodes.

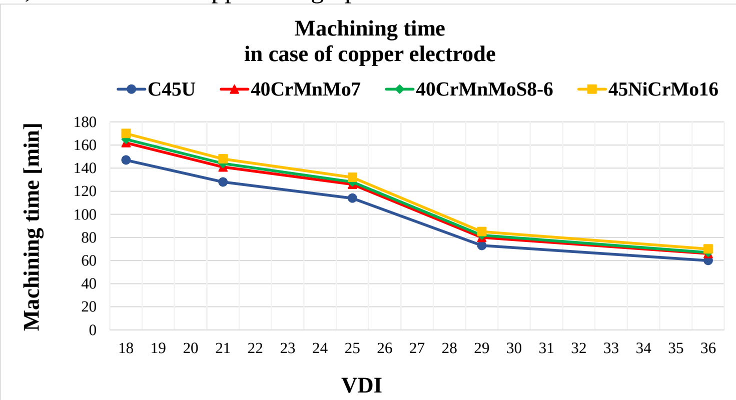

Figure 10 – Variation of machining times depending on the VDI grade in the case of a copper electrode

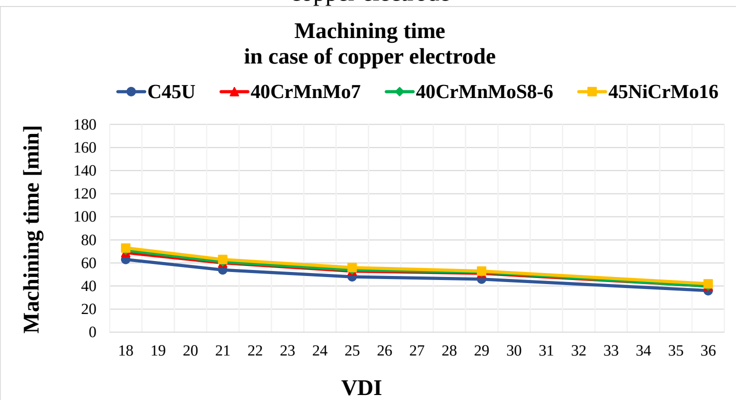

Figure 11 – Variation of machining times depending on the VDI grade in the case of a graphite electrode

From Figures 10 and 11, it can be seen that as the VDI grades increase, the machining time decreases, i.e., the machining becomes more productive. For the tool steels studied, for both copper and graphite electrodes, it can be said that the proportion of alloying elements in the material being machined is related to the machining time. The less alloying elements the material tested contained, the shorter the time required for spark erosion. Accordingly, cavities made on unalloyed C45U steel took the least time to machine, and those made on 45NiCrMo16 steel with the most alloying elements took the longest. The most striking difference was observed between the two electrode materials The productivity of the graphite electrode is almost twice that of the copper electrode, which means that the spark cutting process takes significantly less time than with copper.

5. CONCLUSIONS

Summarising the results of the research work on the comparison of tool steels of different alloys machined by EDM, the following conclusions can be drawn:

- Regarding the amplitude roughness parameters (R_a and R_z), the surface roughness value deteriorates with increasing VDI grades. In the tested range, small roughness differences can be observed between the individual tool steels. Increasing the amount of alloying elements slightly worsens the surface roughness. Regarding the two types of electrode materials, it can be said that the roughness of the surfaces produced with a graphite electrode is usually greater than that produced with a copper electrode.
- In the case of EDM surfaces, the mean roughness depth R_z varied analogously to the average roughness R_a. Based on the measurement results, the relation $R_z \approx (6 \div 13) \cdot R_a$ can be written for their relationship.
- According to the material ratio parameter (R_{mr}) determined at a depth of c = 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. The effect of the amount of alloying elements is more evident for the R_{mr} parameter than for the R_a and R_z parameters. For smaller alloying amounts, more favourable (higher) material ratio parameter values are obtained.
- In connection with the examination of the machining times, it can be said that increasing the VDI grades reduces the processing time, i.e. increases the material removal rate. From this point of view, the less alloyed materials were more machinable. Regarding the two electrode materials, a significant difference can be shown between graphite and copper. The material removal rate of graphite is much higher than that of copper, which means that the machining times for copper are about twice as long as for machining with a graphite electrode.

Summarizing our findings, it can be said that the surface roughness parameters deteriorate as the VDI grades increase (R_a and R_z increase, R_{mr} decreases). At the same time, increasing the VDI grade reduces the machining time, i.e. increases productivity. No significant differences were found for the tool steel materials machined in the test. However, unalloyed or less alloyed steels could be machined more productively and with a better surface quality. In terms of roughness, the two electrode materials (copper and graphite) showed no significant differences, but the productivity of graphite was about twice that of copper electrodes. We intend to continue the research work by evaluating further profile and 3*D* roughness parameters.

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ДОСЛІДЖЕННЯ ЕЛЕКТРОРОЗРЯДНОЇ ОБРОБКИ ІНСТРУМЕНТАЛЬНИХ СТАЛЕЙ ЗА ШОРСТКІСТЮ ОБРОБЛЮВАНИХ ПОВЕРХОНЬ

Анотація. *При електророзрядній обробці (електроерозійна або іскрова ерозія) шорсткість оброблюваної поверхні відіграє дуже важливу роль у застосовності процесу. Дана робота присвячена порівняльному дослідженню електророзрядної обробки інструментальних сталей на* *основі характеристик шорсткості оброблюваних поверхонь. Інша мета дослідження полягає в тому, щоб з'ясувати, які інструментальні матеріали (електродний матеріал, мідь або графіт) є найбільш ефективними для досягнення найкращої можливої мікрогеометрії поверхні. Що стосується параметрів амплітудної шорсткості (R_a і R_z), то значення шорсткості поверхні погіршується зі збільшенням марок VDI. У випробуваному діапазоні можна спостерігати невеликі відмінності шорсткості між окремими інструментальними сталями. Збільшення кількості легуючих елементів дещо погіршує шорсткість поверхні. Щодо двох типів електродних матеріалів можна сказати, що шорсткість поверхонь, отриманих за допомогою графітового електрода, зазвичай більша, ніж шорсткість, отримана мідним електродом. У випадку електроерозійних поверхонь середня глибина шорсткості R_z змінювалася аналогічно середній шорсткості R_a. За результатами вимірювань відношення $R_z \approx (6 \div 13) R_a$ можна записати для їх відносин. Відповідно до параметра співвідношення матеріалу (R_{mr}), визначеного на глибині c = 10 мкм, найкращі експлуатаційні та зносостійкі властивості досягаються на 18 рівні стандарту VDI, які безперервно погіршуються зі збільшенням рівня, а результати, отримані на кожній мішені інструменту, показують зменшувану різницю зі збільшенням рівня. Вплив кількості легуючих елементів більш очевидно для параметра R_{mr}, ніж для параметрів R_a і R_z. При менших кількостях легування виходять більш вигідні (більш високі) значення параметрів співвідношення матеріалів. У зв'язку з вивченням термінів механічної обробки можна сказати, що збільшення рівня VDI скорочує час обробки, тобто збільшує швидкість зняття матеріалу. З цієї точки зору, менш леговані матеріали були більш оброблюваними. Що стосується двох електродних матеріалів, то можна показати значну різницю між графітом і міддю. Швидкість видалення матеріалу графіту набагато вища, ніж у міді, а це означає, що час обробки з допомогою міді приблизно вдвічі довший, ніж для обробки графітовим електродом. На підставі даних проведених експериментів з обробляння і подальших вимірювань будуть зроблені висновки щодо оброблюваності випробовуваних інструментальних сталей і застосовності використовуваних електродних матеріалів.*

Ключові слова: *електроерозійна обробка; мідні, графітові електроди; функціональні показники шорстості.*