UDC 621.9.048 **doi: 10.20998/2078-7405.2025.103.07**

INVESTIGATION OF FUNCTIONAL SURFACE ROUGHNESS PARAMETERS ON STEEL SURFACES MACHINED BY ELECTRO-DISCHARGE MACHINING

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Received: 18 November 2025/ Revised: 26 November 2025/ Accepted: 29 November 2025 / Published: 15 December 2025

Abstract. *The surface quality produced by electrical discharge machining (EDM) nowadays allows these surfaces to be used directly as functional surfaces—often without the need for post machining—such as in the production of plastic moulding tools. This highlights the importance of surface quality assessment not only through traditional amplitude parameters but also through so-called functional roughness parameters. This paper presents the results of studies in which EDM machined tool steels were investigated using functional surface roughness parameters. Such parameters effectively characterize the operational behaviour and applicability of machined surfaces.*

Keywords: *electrical discharge machining (EDM); surface texture; functional roughness parameters; topological map.*

1. Introduction

Electrical discharge machining is widely used in tool manufacturing, particularly for producing plastic injection moulds. Fine structured surface quality (texture or pattern) is required on steel mould plates and inserts, which strongly influences the aesthetic quality of the moulded plastic components. The precision of the surface texture must be reproduced depends on several factors, including the material properties of the workpiece, the tool electrode material, the construction of the EDM machine, and numerous technological parameters.

EDM-machined surfaces consist of overlapping, irregularly located craters, whose formation is influenced by several parameters—voltage, current intensity, and pulse duration. Several authors have analysed EDM surface roughness as a function of technological parameters [1,2], but usually only in terms of traditional amplitude parameters (R_a, R_z, R_t).

Because crater formation results from pulsed melting and vaporisation, and because re-solidified material creates an irregular height distribution, amplitude roughness values are less informative. Therefore, it is more appropriate to analyse functional roughness parameters such as R_{sk}/R_{ku} and R_{mr}, which better describe whether the surface is peak- or valley-dominated and to what extent it can function as a real contact surface [3].

2. Material ratio and functional surface parameters

One of the most frequently used functional parameters is the material ratio (R_{mr}).

R_{mr} is defined as the ratio of the material cross-sections cut at a specified depth (p) below the surface peak level to the evaluation length (l_r) (Figure 1) [4]. Given as a percentage, a higher R_{mr} value generally indicates more favourable operational properties. Mathematically:

$$R_{mr(c)} = \frac{\sum_{i=1}^{n} b_i}{l_r} \tag{1}$$

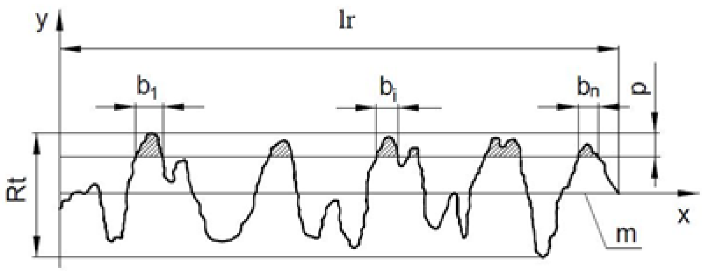

Figure 1 – Interpretation of the material ratio (R_{mr})

Skewness (R_{sk}) describes the asymmetry of the profile height distribution curve about its mean line:

$$R_{sk} = \frac{1}{R_q^3} \cdot \frac{1}{l_r} \int_0^{l_r} y(x)^3 dx \tag{2}$$

where R_q is the root-mean-square roughness:

$$R_q = \sqrt{\frac{1}{l_r} \int_0^{l_r} y(x)^4 dx} \tag{3}$$

Skewness (R_{sk}) indicates whether deviations are symmetric about the mean line or dominated by peaks (positive) or valleys (negative). For Gaussian surfaces—

where the distribution of height values is symmetric—$R_{sk} = 0$. R_{sk} is negative when the height-distribution curve extends more on the side above the mean plane, and positive in the opposite case (Figure 2). Negative skewness values indicate that the machined surface texture has good load-bearing capacity and is more wear-resistant. This parameter has very important technical and practical significance for real working surfaces.

Kurtosis (R_{ku}) characterizes the peakiness, sharpness, and thus the dispersion (range of dispersion) of the height distribution. Definition:

$$R_{ku} = \frac{1}{R_q^4} \cdot \frac{1}{l_r} \int_0^{l_r} y(x)^4 dx \quad (4)$$

For the Gaussian surfaces, $R_{ku} = 3$. A high R_{ku} value usually indicates prominent peaks or valleys (or possibly both) (Figure 2). If $R_{ku} > 3$, surfaces sliding against each other will be characterized by intense wear. If $R_{ku} < 3$, the distribution of surface irregularities is much more favourable. In this case, the surface can be described as having a full, plateau-like profile.

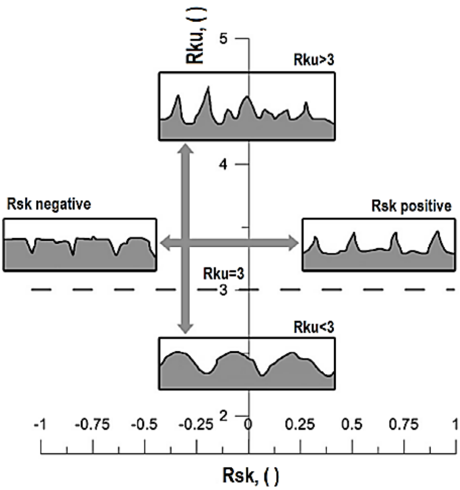

Figure 2 – Illustration of skewness (R_{sk}) and kurtosis (R_{ku})

In the present study, the material ratio, skewness, and kurtosis parameters were analysed on EDM-machined plastic mould tool steels.

3. Experimental conditions

Experiments were carried out on a Neuar CNC-C50 EDM machine-tool. Workpieces were mounted in a vise, and petroleum was used as the dielectric fluid.

Four tool steels commonly used for plastic injection moulding were investigated. Each specimen was machined by die-sinking EDM. The chemical composition of the steels is shown in Table 1.

The test pieces were rectangular plates (115 × 140 × 15 mm), pre-ground and hardened for more efficient EDM. Each sample contained 5 mm depth cavities (Figure 3), machined at different VDI grades using two electrode materials.

Table 1 – Chemical composition machined tool steels

Material	C, %	Si, %	Mn, %	Cr, %	Mo,%	S, %	Ni,%
40CrMnMo7	0,40	0,30	1,50	1,90	0,20		
40CrMnMoS8-6	0,40	0,40	1,50	1,90	0,20	0,08	
45NiCrMo16	0,48	0,23	0,40	1,30	0,25		4,00
C45U	0,45	0,30	0,70				

Figure 3 – Test specimen with cavities machined by EDM using two different tools

Each specimen contained five cavities produced at different VDI grades using two electrode types. On modern EDM machines, technological parameters influencing machining quality and efficiency—such as discharge current, voltage, and pulse duration—cannot be set manually; instead, the machine automatically selects them based on the chosen VDI grade (typically ranging from VDI 0 to VDI 45) [5]. The VDI grades chosen for this study were 18, 21, 25, 29, and 36..

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.

The surface roughness of the machined cavities was measured in the laboratory of the Institute of Manufacturing Science at the University of Miskolc using an AltiSurf 520 three-dimensional surface topography device.

4. Experimental results

From the results of the EDM experiments, conclusions can be drawn about the effect of the set VDI grade, the different electrode materials, and the machined steel grades on the profile roughness in terms of the operational roughness parameters.

Figures 4 and 5 show the change in the material ratio parameter (R_{mr}) of the cavities made with copper and graphite electrodes at each VDI level. The material ratio (R_{mr}) is used to characterize the operating and wear properties of surfaces. The higher the percentage R_{mr} value of a given surface, the more favourable its operating properties. During the tests, the material ratio parameter values were determined at a depth of c = 10 μ*m*.

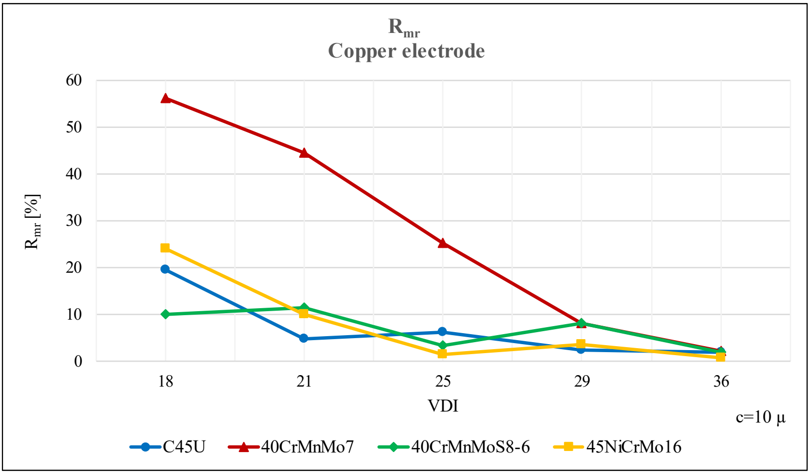

Figure 4 – Change in the R_{mr} parameter as a function of the VDI grade for copper electrodes

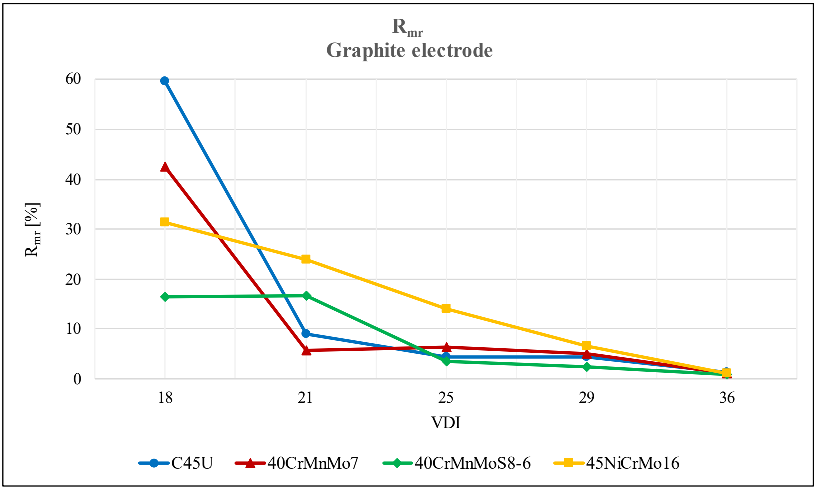

Figure 5 – Change in the R_{mr} parameter as a function of the VDI grade for copper electrodes

Figures 4 and 5 show that the most favourable operating properties are achieved at VDI grade 18 and that, as the VDI grades increase, the surface characteristics deteriorate and the difference in the material ratio parameter between the individual steels decreases, regardless of the tool and workpiece material. In the case of copper electrodes, outstanding properties can be achieved at EDM 40CrMnMo7 material, and in the case of graphite, the same can be said for C45U and 45NiCrMo16 steel. At VDI level 18, the lowest percentage values was obtained for the 40CrMnMoS8-6 material, which also contains sulphur alloying. At the other levels, the weaker values vary from level to level.

In addition to the R_{mr} material ratio parameter, the functional parameters R_{sk} skewness and R_{ku} kurtosis also have very important technical and practical significance for real working surfaces. A topological map can be created using the values of the R_{sk} - R_{ku} parameters. The topological map is a series of points plotted on an R_{sk} - R_{ku} plane, which gives the skewness and kurtosis parameters of the measured roughness of the manufactured surface. The corresponding values of R_{sk} and R_{ku} for surfaces produced using different cutting technologies form groups depending on the cutting technology (Figure 6). Surfaces produced using different technologies have different R_{sk} - R_{ku} values [6,7].

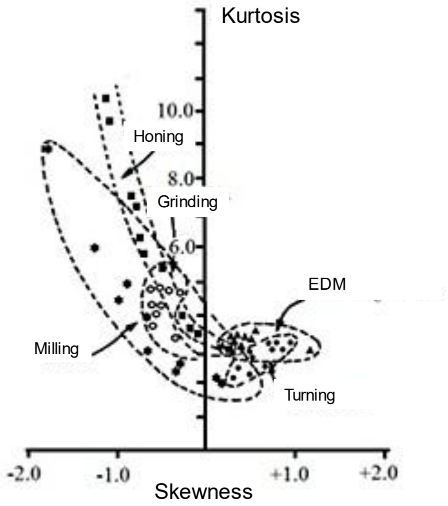

Figure 6 – Topological map of R_{sk} - R_{ku} for surfaces produced using different cutting processes [6]

To evaluate measurement results, a topological map was created from the measured data, also marking the theoretical location of EDM technology (Figures 7 and 8).

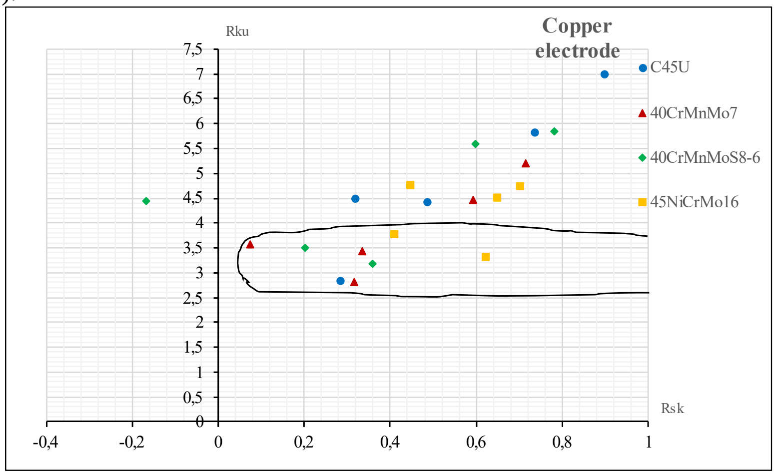

Figure 7 – R_{sk} - R_{ku} topological map for surfaces machined with copper electrodes

Considering that the most favourable properties in terms of operation are given by the parameter pairs R_{sk} - R_{ku} parameter pairs located furthest to the left and below, we can conclude from the measurement results that these data pairs were best achieved on surfaces of 40CrMnMoS8-6 steel with a copper electrode and on surfaces of 45NiCrMo16 steel with a graphite electrode.

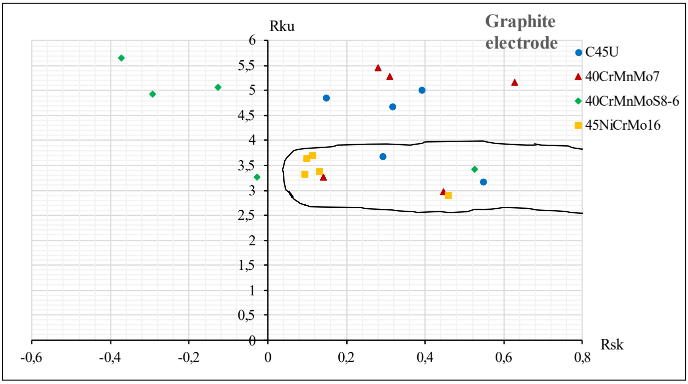

Figure 8 – R_{sk} - R_{ku} topological map for surfaces machined with graphite electrodes

No clear result was obtained for the tool steel with the most unfavourable properties. Examining the technological area of EDM as defined in the literature, it can be said based on the measured values that the measurement points of the material

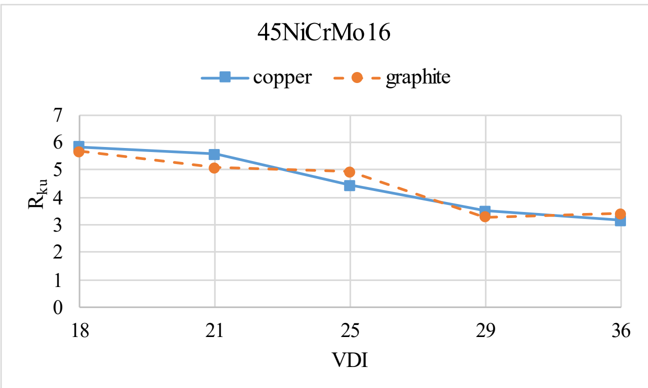

Figure 9 – Variation of R_{ku} peaking as a function of VDI grade on 45NiCrMo16 tool steel

grades with the most favourable properties did not necessarily fall within the theoretically designated area. Figures 9 and 10 show the change in R_{sk} and R_{ku} values as a function of the set VDI grades.

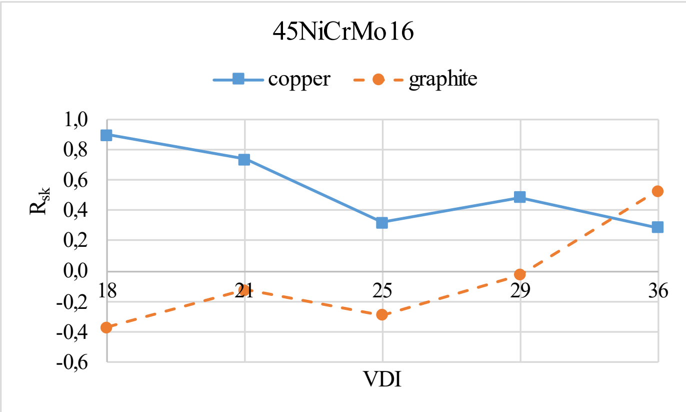

Figure 10 – Variation of R_{sk} skewness as a function of VDI grade on 45NiCrMo16 tool steel

It is interesting to note that the peak value decreases at higher VDI levels, approaching the value of 3, which is considered favourable in the literature. The two types of electrodes produce almost identical results (Figure 9). No clear conclusion can be drawn regarding skewness, as skewness decreases with copper electrodes but increases with graphite electrodes (Figure 10). Further investigation is needed to explain this phenomenon.

5. Conclusions

Based on the evaluation of the experimental results, the following conclusions can be drawn regarding the electro discharge machining (EDM) of tool steels with copper and graphite electrodes:

- With increasing VDI grade, the material ratio (R_{mr}) of the roughness of the machined surfaces clearly decreases. In the range investigated, the most favourable values are achieved at VDI grade 18.
- The machined surfaces of the different tool steels did not show any significant differences in terms of the material ratio (R_{mr}). In the case of copper electrodes, outstanding properties can be achieved when EDM

40CrMnMo7 material, and in the case of graphite, the same can be said for C45U and 45NiCrMo16 steel.

- Increasing the VDI grade reduces the surface roughness kurtosis (R_{ku}) to a favourable value of 3. In this respect, the two types of electrode materials and the different tool steel grades did not show any significant differences.
- The change in skewness (R_{sk}) as a function of the VDI grade is not clear. It clearly increases when machining with a graphite electrode, while it decreases when using a copper electrode.
- The R_{sk} - R_{ku} topological maps created based on the tests partially confirmed the ranges described in the literature as characteristic of electro discharge machining. From this point of view, the most favourable data pairs were achieved on the surfaces of 40CrMnMoS8-6 steel with a copper electrode and 45NiCrMo16 steel with a graphite electrode

Our results prove that changes in VDI grades significantly determine the so-called functional parameters of the roughness of machined surfaces. It has become clear that it is not possible to accurately describe the nature of a surface using a single parameter, so it is necessary to use these functional parameters and their combinations (topographic maps). Further studies are needed to clearly determine the effect of VDI grades.

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ДОСЛІДЖЕННЯ ПАРАМЕТРІВ ФУНКЦІОНАЛЬНОЇ ШОРСТКОСТІ ПОВЕРХНІ СТАЛЕВИХ ВИРОБІВ, ПІСЛЯ ЕЛЕКТРОРОЗРЯДНОЇ ОБРОБКИ

Анотація. *Якість поверхні, отримана електричною розрядною обробкою (EDM), сьогодні дозволяє використовувати ці поверхні безпосередньо як функціональні поверхні – часто без* *потреби у постобробці – наприклад, у виробництві пластикових інструментів для формування. Це підкреслює важливість оцінки якості поверхні не лише за традиційними параметрами амплітуди, а й через так звані параметри функціональної шорсткості. У цій статті представлено результати досліджень, у яких EDM-оброблені інструментальні сталі вивчалися з використанням параметрів функціональної поверхневої шорсткости. Такі параметри ефективно характеризують операційну поведінку та застосовність оброблених поверхонь. На основі оцінки експериментальних результатів можна зробити деякі висновки щодо електророзрядної обробки (EDM) інструментальної сталі за допомогою мідних і графітових електродів. Зі збільшенням класу VDI співвідношення матеріалу (R_{mr}) до шорсткості оброблених поверхонь явно зменшується. У дослідженому діапазоні найсприятливіші значення досягаються на рівні VDI 18. Оброблені поверхні різних інструментальних сталевих виробів не мали суттєвих відмінностей у співвідношенні матеріалів (R_{mr}). У випадку мідних електродів видатні властивості можна досягти при використанні матеріалу EDM 40CrMnMo7, а у випадку графіту те саме можна сказати про сталі C45U та 45NiCrMo16. Підвищення ступеня VDI знижує куртоз шорсткості поверхні (R_{ku}) до сприятливого значення 3. У цьому сенсі два типи матеріалів електродів і різні сорти інструментальної сталі не мали суттєвих відмінностей. Зміна кососсті (R_{sk}) як функція ступеня VDI залишається незрозумілою. Вона явно зростає при обробці графітовим електродом, тоді як зменшується при використанні мідного електрода. Топологічні карти R_{sk} -R_{ku}, створені на основі випробувань, частково підтвердили діапазони, описані в літературі як характерні для електророзрядної обробки. З цієї точки зору найбільш сприятливі пари даних були отримані на поверхнях сталі 40CrMnMoS8-6 з мідним електродом і сталі 45NiCrMo16 з графітовим електродом Наші результати доводять, що зміни ступенів VDI суттєво визначають так звані функціональні параметри шорсткості оброблених поверхонь. Стало зрозуміло, що неможливо точно описати природу поверхні одним параметром, тому необхідно використовувати ці функціональні параметри та їхні комбінації (топографічні карти). Потрібні подальші дослідження, щоб чітко визначити вплив оцінок VDI.*

Ключові слова: *електроерозійна обробка (EDM); текстура поверхні; параметри функціональної шорсткості; топологічна карта.*