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Original Research

THE EFFECT OF SELECTED WEDM PARAMETERS ON CUT SURFACE QUALITY OF 2017A ALUMINUM

WPŁYW WYBRANYCH PARAMETRÓW ELEKTRODRĄŻENIA NA JAKOŚĆ POWIERZCHNI CIĘCIA ALUMINIUM 2017A

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Abstract

With the wire electrical discharge machining (WEDM), good quality machined surfaces can be achieved. The WEDM is worth considering for machining fasteners used in assembly processes. This paper presents a study of the WEDM cutting process of aluminum 2017A using an WEDM machine of the FR 400 type. After applying different cutting speeds, the characteristics of the cut surface were evaluated. Despite some differences in the shape of surface profiles and surface morphology noted after WEDM cutting at different speeds, the analysis of variance concluded that the WEDM cutting speed in the studied variation range of 23-125 µm/s has no significant effect on surface roughness. At the highest speed studied, machining efficiency can be increased, affecting cost and energy reduction, while maintaining an acceptable and comparable level of surface quality after WEDM cutting.

Keywords: aluminum 2017A, fasteners for assembly, WEDM, surface characteristics, analysis of variance

Streszczenie

Dzięki obróbce elektroerozyjnej można uzyskać dobrą jakość obrabianych powierzchni. Warto rozważyć zastosowanie obróbki elektroerozyjnej do obróbki elementów złącznych wykorzystywanych w procesach montażowych. W artykule przedstawiono badania procesu cięcia elektroerozyjnego aluminium 2017A z zastosowaniem elektrodrążarki typ FR 400. Po zastosowaniu zróżnicowanej prędkości obróbki poddano ocenie stan powierzchni cięcia. Pomimo zauważonych pewnych różnic w kształcie profili powierzchni i morfologii powierzchni po cięciu elektroerozyjnym z różnymi prędkościami, to w wyniku analizy wariancji stwierdzono, że prędkość cięcia poprzez elektrodrążenie w badanym zakresie zmienności 23-125 µm/s nie wywiera istotnego wpływu na chropowatość powierzchni. Przy największej badanej prędkości można zwiększyć wydajność obróbki, wpływając na zmniejszenie kosztów i energii, zachowując akceptowalny i porównywalny poziom jakości powierzchni po cięciu elektroerozyjnym.

Słowa kluczowe: aluminium 2017A, elementy złączne w montażu, obróbka elektrodrążeniem, stan powierzchni, analiza wariancji

1. Introduction

Automation of the assembly process specifically requires high quality components from which a machine unit or finished product is assembled. Analyzing the assembly process, it can be concluded that individual operations do not affect the properties of the assembled part in the same way. Taking into account the design of the assembled part or assembly, among other things, the quality of the fasteners connecting the individual parts of the structure is very important. The quality of fasteners should be understood as such features as the type of materials and its properties, as well as the design and finish. One of the materials used for fasteners is aluminum type 2017A, which, due to the addition of copper and magnesium, is characterized by relatively high hardness and high strength (Kuczmaszewski et al., 2015; Skrzypek, 2019). As previously mentioned, the reliability of the assembly will be affected by the way the fasteners are finished, since technological processing has a significant impact on the quality of the surface layer. One of the first operations that is performed after supplying suitable material is the cutting operation. There are many cutting methods from traditional saw cutting to laser or water jet cutting. One of the more interesting cutting techniques is electro-discharge cutting, which makes it possible to realize machining of parts with complex shapes requiring high dimensional accuracy. It is considered the most precise cutting method, but to achieve the required dimensional accuracy and surface quality, several machining passes must be made along the cutting profile (Ho et al, 2004). The WEDM is most often used for machining tempered steels, tool steels, carbides or other materials usually of high hardness, but due to the advantages of WEDM such as high precision and good surface quality after machining, it is worth considering its application for machining other materials.

In the WEDM cutting process, the area between the wire electrode and the workpiece is subjected to thermal effects that cause overmelting and burning of the material, resulting in changes in the structure and surface properties of the cut workpiece. Three characteristic layers can be distinguished in the microstructure of the surface layer after WEDM (Mazurkiewicz, 2010; Oniszczuk et al. 2015):

- the first is the so-called white layer - it is formed on the surface of the material due to the solidification of previously melted metal that has not been removed from the cutting gap;
- the next layer, located directly below the white layer, is the thermal influence layer;
- the third layer is the so-called tempered layer.

Tensile stresses are present in the surface layer after the WEDM process, resulting from the shrinkage of the heated material. The value of the stresses is determined by the energy and duration of individual electrical discharges. The presence of stresses in the surface layer can contribute to the formation of microstructure defects in the form of craters and micro-cracks (Mazurkiewicz, 2010). The geometric structure of the surface after the WEDM cutting process is random in nature with a significant density of surface profile elements (Oniszczuk et al. 2015).

In the WEDM cutting process, a number of process variables can be distinguished that affect machining performance, electrode wear, thickness of the heat affected layer, surface roughness and changes in the structure of the material being cut. These factors are related to the energy conditions of the process, the chemical composition and properties of the dielectric, working electrode, workpiece material, stiffness and parameters of the cutting machine, among others (Mazurkiewicz, 2010).

This paper presents the results of a study on the WEDM cutting of 2017A aluminum, especially on the effect of cutting speed on the cut surface quality. The WEDM cutting is typical to process hard material but considering the capabilities of the process, possible advantages in cutting a relatively soft material such as aluminum were investigated.

2. Research methodology

In the article the process of cutting aluminum 2017A by wire electrical discharge machining is examined. Aluminum 2017A belongs to a group of aluminum-copper-magnesium alloys called duralumin or copper durals. The heat treatment of this alloy mainly consists of precipitation hardening, which includes supersaturation and aging processes (Kuczmaszewski et al., 2015; Skrzypek, 2019). The chemical composition of aluminum 2017A is given in Table 1.

Table 1. Chemical composition of aluminum 2017A (http, 2024; PN-EN, 2022-11)

Si (%)	Fe (%)	Cu (%)	Mn (%)	Mg (%)
0,20-0,80	≤ 0,70	3,50-4,50	0,40-1,0	0,40-1,0
Cr (%)	**Zn (%)**	**Zr+Ti (%)**	**others (%)**	**Al (%)**
≤ 0,10	≤ 0,25	≤ 0,25	≤ 0,15	rest

Table 2 shows the properties of aluminum 2017A. Aluminum 2017A is used for die forging or cast parts, mainly in the aerospace, automotive, engineering and construction industries. Parts made from this alloy can operate not only at ambient temperatures, but also at higher temperatures, due to increased heat resistance caused by the addition of manganese, among other things.

Table 2. Selected properties of aluminum 2017A (Kuczmaszewski et al., 2015; http, 2024)

Hardness after supersaturation and natural aging	110 HB
Hardness after annealing	55 HB
Supersaturation temperature	490-510ºC
Aging temperature	170-190ºC
Density	2,8 g/cm^3
Coefficient of linear expansion	$23 \cdot 10^{-6}$ K^{-1} (20ºC)

Since aluminum 2017A is characterized by relatively high hardness and high strength (Kuczmaszewski et al., 2015; Skrzypek, 2019), it is also used for fasteners.

The process of cutting the 2017A material was carried out using the FR 400 numerically controlled WEDM cutting machine. Molybdenum wire with a diameter of 0.18 mm was used as the electrode. The dielectric fluid was deionized water. Fig. 1 shows photos of the FR 400 WEDM cutter.

Fig. 1. Photos of the FR 400 machine (Jamróz, 2022)

According to the machine specification (manual, 2021), the roughness parameter Ra after one machining pass should be less than or equal to 2 μm, while after several passes Ra should be less than or equal to 0.8 μm.

An aluminum cube of material was subjected to WEDM cutting at four different speeds. A so-called single machining pass of the WEDM cut was performed. A photo of the cut material is shown in Fig. 2.

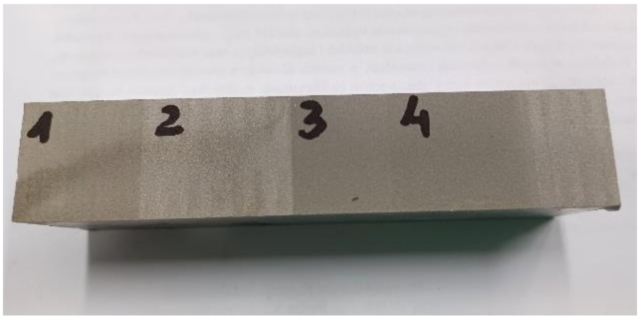

Fig. 2. Photo of aluminum 2017A after WEDM cutting

In the experimental study, a variable cutting speeds [μm/s] were adopted. The current I [A] was automatically changed based on the cutting speed setting.

Electrical discharge cutting was performed with a single pass. The surface after cutting is usually subjected to subsequent machining operations, since the obtained surface roughness parameters are not, as far as values are concerned, equal to those expected for the finished product. However, too high values of surface roughness after WEDM cutting can affect the subsequent machining process and prolong the production process, or increase production costs by requiring additional machining operations. Therefore, the selection of appropriate process parameters of the implemented operations becomes so important.

A statistical method with one-factor analysis of variance was used to quantitatively assess the significance of the selected technological parameter effect. More details about the method and the example of application are presented in (Gałda et al., 2022). The input factor was the cutting speed at four levels of variation in the range of 23 - 125 μm/s (Table 3).

Table 3. The WEDM cutting process parameters

Cutting surface (fig. 2)	Aluminum 2017A	
	Cutting speed [μm/s]	Current I [A]
1	60	2
2	125	3
3	35	1÷2
4	23	1

The output factors were the selected surface roughness parameters after WEDM cutting. A significance level of $\alpha = 0.05$ was adopted.

Surface roughness was measured using a Surtronic 25 stylus profilometer, while selected surface roughness parameters were calculated using TalyProfile Lite 6 software. Measurements of each cut surface were performed with three times repetition on a measuring section of 8 mm. Mainly the amplitude parameters (Rp, Rv, Ra) were analyzed, but given the presence of characteristic paths on the cut samples, the longitudinal parameter RSm was also analyzed.

A Phenom Pro scanning electron microscope was used to observe the surface of the samples after WEDM cutting. The SEM images of the surfaces after WEDM cutting were taken at 510x magnification.

3. Results and their analysis

Figure 3 shows selected representative primary profiles of the surface after WEDM cutting at varying speeds. The results of the measurements of selected roughness parameters are shown in Table 4. Analyzing the surface profiles, it can be seen that they are all characterized by significant surface irregularities with sharply ended steep peaks and depressions.

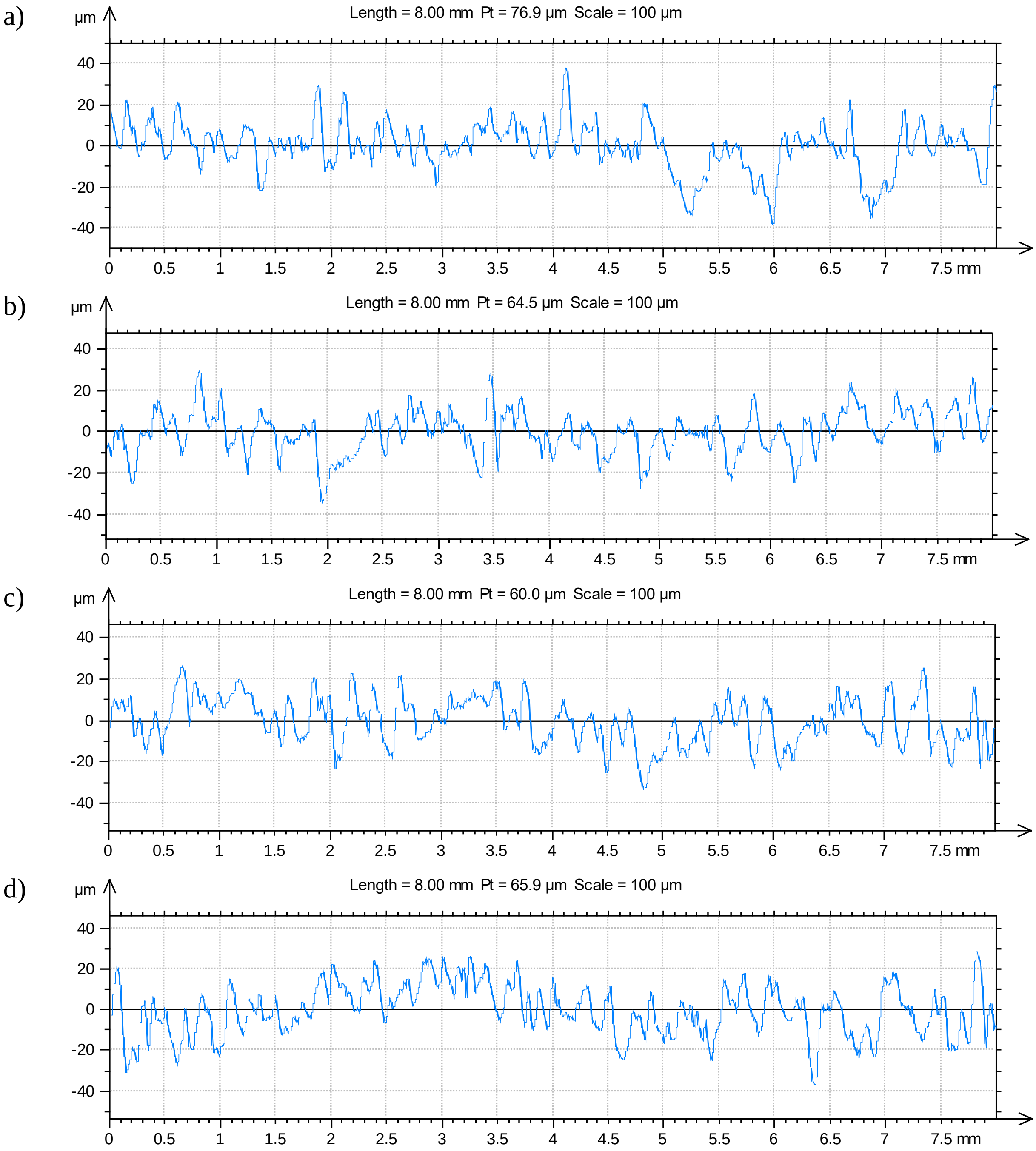

Fig. 3. Selected surface profiles after WEDM cutting with different speeds: 23 μm/s (a), 35 μm/s (b), 60 μm/s (c), 125 μm/s (d)

On the surface profiles (Fig. 3 a, b) after WEDM cutting at lower speeds the valleys of greater width randomly appear than those found on the compared surface profiles (Fig. 3 c, d), where the cutting speed was several times higher. Comparing selected amplitude parameters of surface roughness, it can be concluded that with increasing cutting speed in most cases their value increases (Table 4).

The average value of the Ra parameter, which presents the average deviation of the profile from the mean line (PN-EN ISO, 2022-06), increases by about 18% as the cutting speed increases. The increase in Ra is mainly due to an increase in the value of the maximum depressions in the profile of the Rv surface (increase of about 16.7%) as the cutting speed increases. The parameter Rp, which determines the highest peak of the profile, increased in value by about 0.7% with increased WEDM cutting speed. The distances between the elements of the profile were also examined, as characteristic paths of varying width were observed on the cutting surfaces. The values of the longitudinal roughness parameter RSm changed with the change in cutting speed, but no significant correlations between these parameters were noted.

Table 4. Measured values of selected parameters of surface profiles after WEDM with average and standard deviation values

Cutting speed [µm/s]	Surface roughness parameters			
	Ra [µm]	Rp [µm]	Rv [µm]	RSm [mm]
23	6,43	17,1	16,6	0,193
	5,74	15,8	15,9	0,196
	6,33	20,8	17,5	0,18
average	**6,167**	**17,9**	**16,7**	**0,19**
standard deviation	0,37	2,59	0,80	0,01
35	6,37	18,5	18,9	0,178
	5,89	18	14	0,16
	6,25	17	18,2	0,218
average	**6,17**	**17,83**	**17,03**	**0,185**
standard deviation	0,25	0,76	2,65	0,03
60	6,93	17,7	17,1	0,189
	7,69	17,6	22,2	0,202
	7,25	19,9	18,8	0,211
average	**7,29**	**18,4**	**19,37**	**0,201**
standard deviation	0,38	1,30	2,60	0,01
125	6,91	15,9	17	0,194
	7,45	18,3	19,8	0,19
	7,54	19,9	21,7	0,18
average	**7,3**	**18,03**	**19,5**	**0,188**
standard deviation	0,34	2,01	2,36	0,01

Analyzing the results, it was noted that the dimensions of the standard deviation from the mean value of the parameters Rp and Rv, as well as RSm, are relatively large when compared to the dimension of the change in the values of these parameters when the cutting speed is changed (fig. 4 b-d). Only the standard deviation from the mean value of the Ra parameter is relatively small compared to the change in Ra values (Fig. 4a), characterizing the surface profiles after WEDM cutting at different speeds. Here it should be noted that the Ra parameter is a parameter, presenting the average of many measured points, so some important relationships may be lost (unnoticed). In such a situation, it is worth checking whether the studied technological parameter (WEDM cutting speed) significantly affects the selected output factors, using statistical methods. In order to assess whether the difference in the value of roughness parameters at different cutting speeds is significant, a one-way analysis of variance of the obtained surface roughness results was applied.

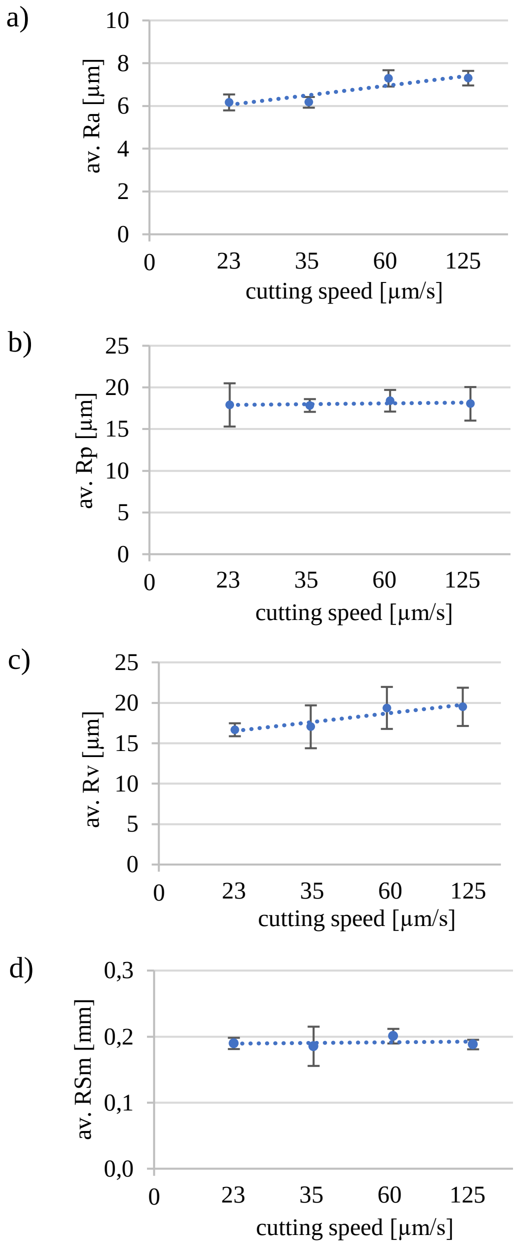

Fig. 4. Average values of Ra (a), Rp (b), Rv (c) and RSm (d) surface roughness parameters versus increasing the cutting speed

The SEM images show some differences in the surface morphology after WEDM cutting. In general, the morphology of the surface after WEDM cutting is characterized by the presence of randomly distributed craters formed by electrical discharges and microcracks formed when the heated material shrinks (Fig. 5). The surfaces cut at lower speeds (Fig. 5 a, b) show craters with irregular shapes and much larger dimensions compared to those observed on surfaces cut at higher speeds (Fig. 5 c, d). The results of the surface morphology observations correlate with the wider valleys observed on the surface profiles when lower cutting speeds were used.

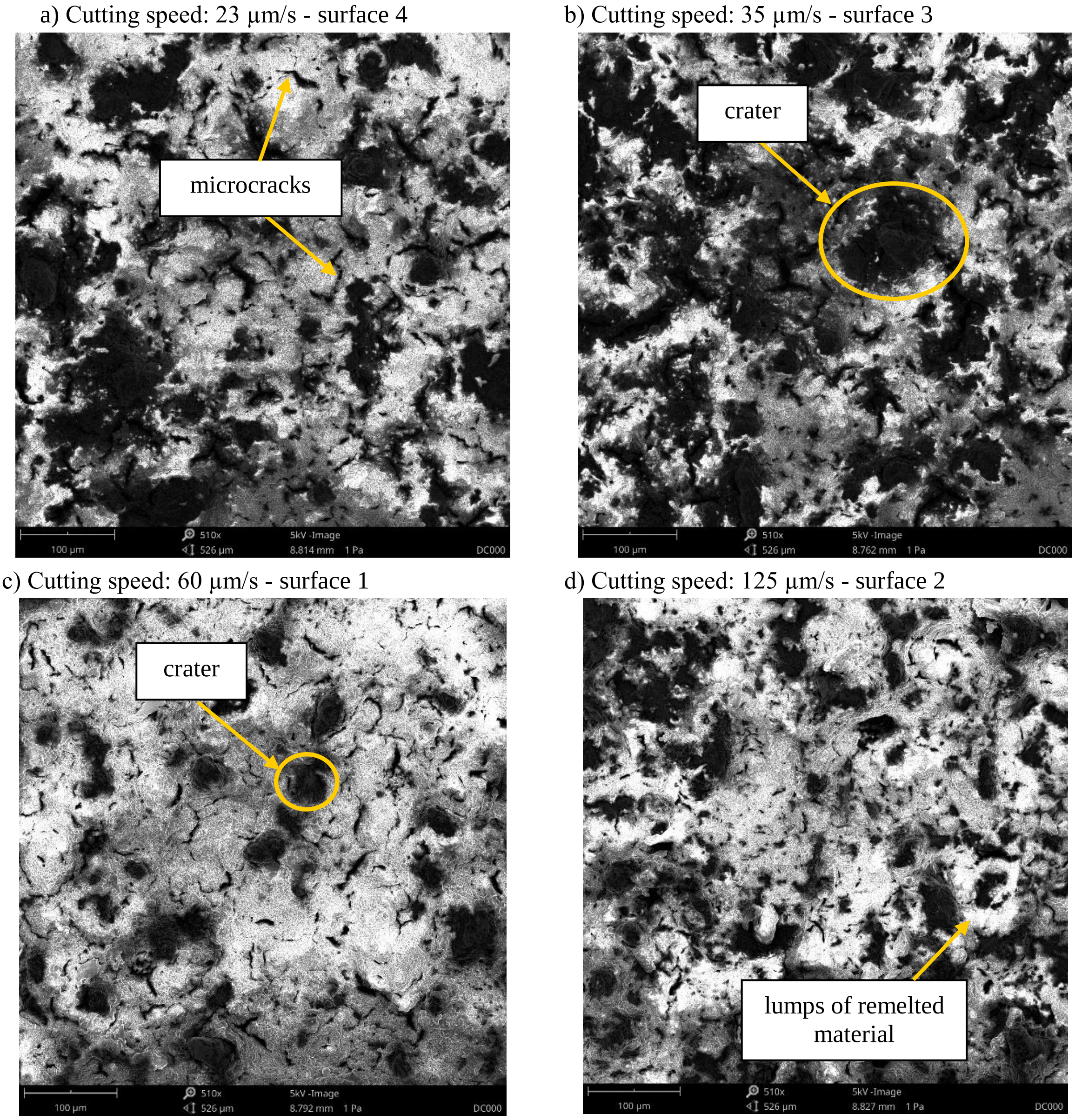

Fig. 5. The SEM images of cutting surfaces with different speeds in the range of 23 μm/s to 125 μm/s (a-d)

In the case of surfaces cut at higher speeds (Fig. 5 c, d), i.e. at the same time at higher current intensity, lumps of remelted material, characteristic of surfaces remelted by thermal interaction, are clearly visible.

Analyzing the variance, it is necessary to assume the null hypothesis H_0, stating that there is no significant effect of cutting speed on the studied surface roughness parameters, i.e. Ra, Rp, Rv and RSm. For each of the analyzed output factors, the analysis is carried out separately. A significance level of α equal to 0.05 was assumed in the study. As a result of the calculations, empirical values of the F index were obtained, which were compared with the critical value of the F_{cr} index, read from the Fisher-Snedecor statistical table. Table 5 shows the results of the one-way analysis of variance for the four selected surface roughness parameters.

Table 5. One factor (cutting speed) variance analysis for surface roughness parameters: Ra, Rp, Rv and RSm

Output parameter	F	F_{cr}	p-value
Ra	10,96	4,07	0,003
Rp	0,06		0,980
Rv	1,35		0,325
RSm	0,48		0,703

In the case of roughness parameters Rp, Rv and RSm, the null hypothesis H_0 of no significant effect of WEDM cutting speed was confirmed. This means that regardless of the change in the value of the technological parameter: cutting speed in the range of 23 μm/s to 125 μm/s, the change in the mentioned roughness parameters is not statistically significant. Only in the case of the Ra parameter the statistical significance of the effect of the cutting speed parameter was shown. However, it should be noted here that the Ra parameter is characterized by the fact that it is determined based on the average of many points, so the analysis based on the variance may be inadequate in this case. Taking into account the obtained results, it should be concluded that the cutting speed of the tested 2017A aluminum material in the range of 23-125 μm/s has no significant effect on the selected surface roughness parameters. Therefore, it is possible to consider increasing the production efficiency by increasing the cutting speed of the WEDM method. Figure 6 presents the cutting length of the 2017A aluminum material of the thickness presented in the article, assuming cutting for 8 hours without interruption.

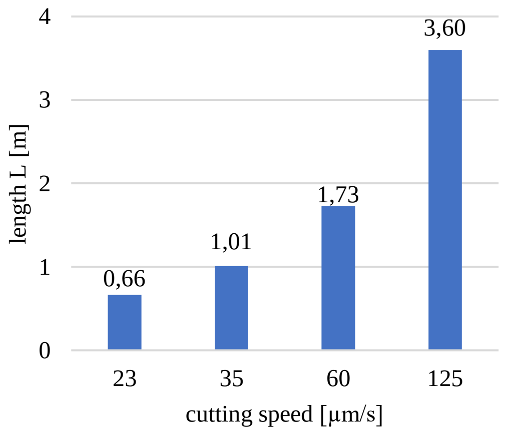

Fig. 6. Length of material that can be cut in one 8-hour shift at different WEDM cutting speeds

With a more than fivefold increase in cutting speed from 23 μm/s to 125 μm/s, a more than fivefold increase in productivity was obtained, which is quite obvious. On the other hand, it is worth noting the savings from reduced energy consumption, since the current is increased only three times from 1 A to 3 A, so in addition to the reduction in machining time, measurable financial savings are also gained. In times of fierce competition in the market, such factors as increased productivity, reduced machining time and energy savings, while ensuring the quality of the product at the appropriate level, gives an advantage over the competitors.

4. Conclusions

Observation of surface profiles and SEM surface images revealed that at low WEDM cutting speeds there are randomly distributed craters with irregular shapes and relatively large dimensions. At higher WEDM cutting speeds, surface irregularities are characterized by a slightly greater maximum depth and there are lumps of remelted material on the surface.

As a result of the analysis of variance of the values of selected surface roughness parameters of aluminum 2017A after WEDM cutting at different cutting speeds, it was found that the cutting speed in the range of 23-125 μm/s has no significant effect on the surface roughness parameters Rp, Rv, RSm.

Since the surface quality determined by the roughness parameters after WEDM cutting does not depend on the cutting speed in the studied range, so there is a possibility to increase productivity, reduce machining time and save energy when realizing WEDM cutting of aluminum 2017A with the highest speed equal to 125 μm/s.

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