Accuracy of machining in the wire electrical discharge machining process with electrodes of varying diameters

Dokładność obróbki w procesie wycinania elektroerozyjnego elektrodami o różnych średnicach

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The WEDM (wire electrical discharge machining) accuracy tests were performed. Electrodes of different diameters were used to cut the blade lock profile of an aircraft engine made from the heat-resistant alloy Inconel 718.
KEYWORDS: WEDM, profile deviation, surface roughness, machining efficiency

In the WEDM process, the dimensional-shape accuracy and roughness of the machined surfaces depend mainly on the machining parameters and the wire electrode diameter [1]. Despite the difficulty of optimizing this machining method and the potential for microcracks, it is still being developed and improved.

The main advantage that determines the development of WEDM is the ability to machine the hard-cutting materials, which is especially useful in the aviation industry [2]. In this industry, high-strength and heat resistant materials, such as difficult-to-machine nickel-based alloy Inconel 718, are used. Usually, the chip or abrasive machining of this alloy requires removal of a substantial volume of material and involves, among others, an accelerated tool wear. Therefore, the alternative methods of machining are sought [3–7], and one of them is WEDM.

The purpose of the study was to compare the accuracy of the electro-discharge cutting of the blade root profile made of Inconel 718 alloy, using electrodes with different wire diameters. For this purpose, an experimental test of the rough and finishing cutting of the blade root profile with wire electrodes of two selected diameters was tested. Subsequently, the measurements of shape deviations and surface roughness were performed.

Test conditions

The tool was an electrode made of brass wire. Electrodes with a diameter of ⌀0.15 mm and ⌀0.25 mm were chosen from the commonly used electrodes.

The samples were in the form of one side of the root profile (fig. 1). The width of the root was 30 mm.

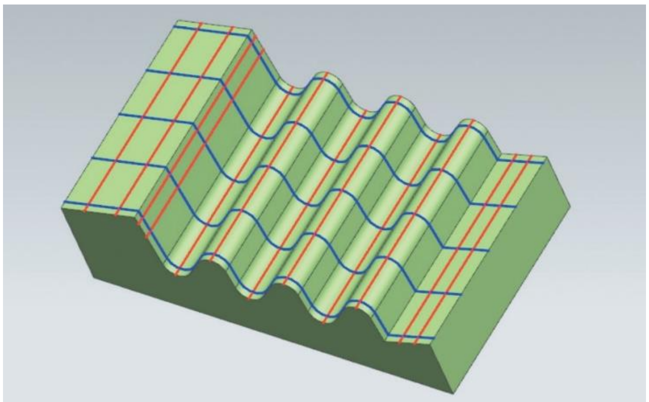

Fig. 1. Workpiece with marked measuring grid

For wire electrodes with a diameter of ⌀0.15 mm, 6 samples were made and for wire electrodes with diameter ⌀0.25 mm, 5 specimens were prepared (according to steel machining technology [8]) with variable number of finishing passes (table I).

TABLE I. Machining parameters

Number of the sample	1		2		3	
Diameter of the wire, mm	0.15	0.25	0.15	0.25	0.15	0.25
U_c, V	46	43	55	57	62	51
I_c, A	105	170	84	179	82	180
t_{off}, μs	14	24	20	14	37	18
F_n, N	9	15	10.5	19	10,5	19
f, mm/min	1.1	2.5	4	4.8	3	3.3
Q_v, l/min	~ 9.4	≥ 10	~ 1.4		~ 1.4	
Number of the sample	4		5		6	
Diameter of the wire, mm	0.15	0.25	0.15	0.25	0.15	0.25
U_c, V	69	115	65	75	66	–
I_c, A	15	120	38	115	19	–
t_{off}, μs	6	3	4	2.8	1.2	–
F_n, N	10.5	21	10.5	21	10.5	–
f, mm/min	4	4.8	2	4.3	3.6	–
Q_v, l/min	~ 1.4		~ 1.4		~ 1.4	–

Legend: U_c – average value of discharge voltage, I_c – value of current peak during discharge, t_{off} – break time, F_n – wire tension force, f – feedrate, Q_v – dielectric volumetric consumption

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The first sample was made roughly in one pass. Machining of other samples was extended by an additional finishing pass. Table I shows parameters of the last pass of the electrode for each sample. Due to the lack of guidelines for the WEDM machining of alloy Inconel 718, the parameters set for steel [8] were used.

Machining was performed on the Mitsubishi FA10S electro-discharge cutting machine. Hioki CT6843 current probe, Rigol RP1300H voltage probe and Rigol DS1074Z oscilloscope were included. The cutting process was performed with the Adaptive Control off and the PM anti-breaking control, immersed in a dielectric that was demineralized water. Machine positioning error was 1 μm.

Measurement results

Voltage and current waveforms have been characterized by numerous arc and anti-short-circuit discharges. This is due to, among other, a large number of machining products that reduce dielectric resistance and destabilize processing conditions in the working gap [9]. This is a characteristic phenomenon when electric-discharge cutting of Inconel 718. In addition, the influence on the waveforms had the need to cut off the adaptive control due to the machining with the use of an electrode with a diameter of less than 2 mm, and short break times t_{off} that could have caused incomplete deionization of the plasma channel, leading to another discharge at the same location.

Deviation measurements of the blade root profile were made on the Mahr XC20 conturograph. Fig. 1 shows the measurement grid. Blue color indicates the root profile. Measurements were made 5 times, at equal distances over the entire width of the root. The second measurement path was related to the rewinding direction of the working electrode and was marked red. In the direction of wire rewinding, measurements were made on straight surfaces, outer and inner radii. The measured profiles were compared to the nominal profile obtained from the CAD model. Due to the shape of the root, two measuring tips were used:

- PVC 350×58 mm 6033/1 for measuring deviations of the profile,
- PCV 175-M/8 mm 5660/11 for measuring deviations in the direction of wire rewind.

Deviations of the shape of the examined profiles are shown in fig. 2.

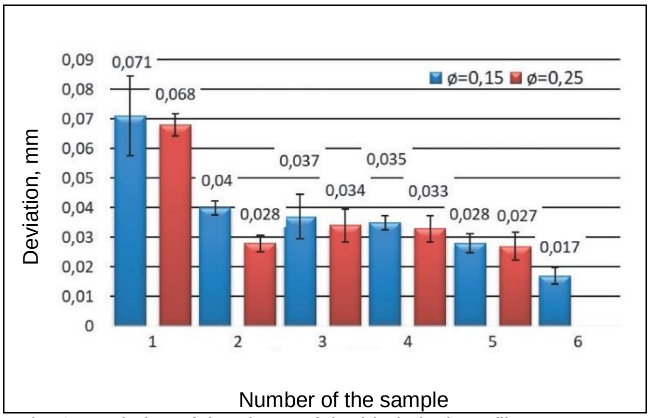

Fig. 2. Deviation of the shape of the blade lock profile

Differences in deviations in the individual passes between electrodes of different diameters were negligible. Additional finishing passages have reduced the deviation value by more than 2 times as compared to roughing. The last machining passage with a diameter of ⌀0.15 mm allowed to reduce the deviation by approximately 37% as compared to the last electrode pass of ⌀0.25 mm.

Deviations measured at the direction of wire rewind (perpendicular to the feed) are shown in fig. 3.

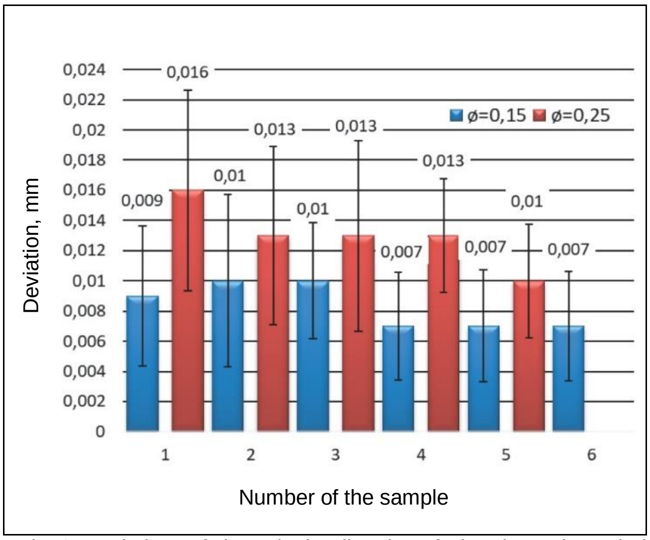

Fig. 3. Deviations of shape in the direction of wire electrode rewind

The use of ⌀0.15 mm wire allowed to reduce the deviation value by up to 50% as compared to the electrode of ⌀0.25 mm. All measurements were characterized by high standard deviation, associated with electrode vibrations and characteristic shape error occurring during machining of round surfaces rounding and getting the form of an hourglass.

Table II shows deviations of shape for characteristic elements of the blade root.

TABLE II. Deviations of shape in the direction of wire electrode rewinding

Number of sample	1		2		3	
Wire diameter, mm	0.15	0.25	0.15	0.25	0.15	0.25
Straight surfaces, mm	0.008	0.012	0.007	0.012	0.005	0.006
External radii, mm	0.004	0.008	0.005	0.008	0.01	0.014
Internal radii, mm	0.014	0.027	0.016	0.019	0.013	0.019
Number of sample	4		5		6	
Wire diameter, mm	0.15	0.25	0.15	0.25	0.15	0.25
Straight surfaces, mm	0.002	0.0085	0.004	0.0071	0.002	–
External radii, mm	0.007	0.0154	0.004	0.0096	0.009	–
Internal radii, mm	0.011	0.0144	0.011	0.0145	0.009	–

The internal radii were characterized by the largest deviations, while straight surfaces by the smallest. A smaller diameter electrode made it possible to obtain smaller deviations for each surface.

Surface roughness measurements were made on the TalyScan 3D profilometer. It was made 3 times on each outer and inner radius of the profile and on straight surfaces. The first measurement was carried out in the symmetry axis of the sample and the other 2 measurements – 3 mm from the outer edge. Measurements of surface roughness parameters *Ra* and *Rz* are presented in fig. 4 and fig. 5.

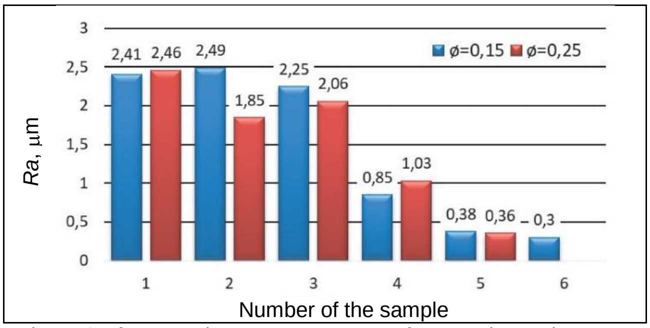

Fig. 4. Surface roughness parameter *Ra* for tested samples

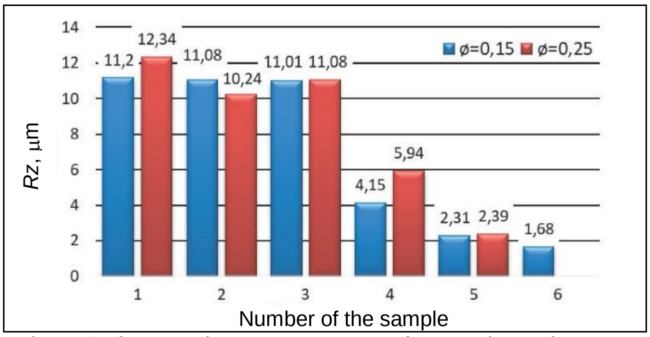

Fig. 5. Surface roughness parameter *Rz* for tested samples

The *Ra* and *Rz* surface roughness values for both working electrode diameters in each pass were comparable. The lowest roughness values were obtained for the last machining pass with a 0.15 mm diameter electrode. The *Rz* roughness was 30% lower than the surface roughness obtained in the 5th machining pass with a 0.25 mm diameter electrode.

Fig. 6 shows geometrical structure of the surface obtained in the last machining pass using wire electrodes of both diameters.

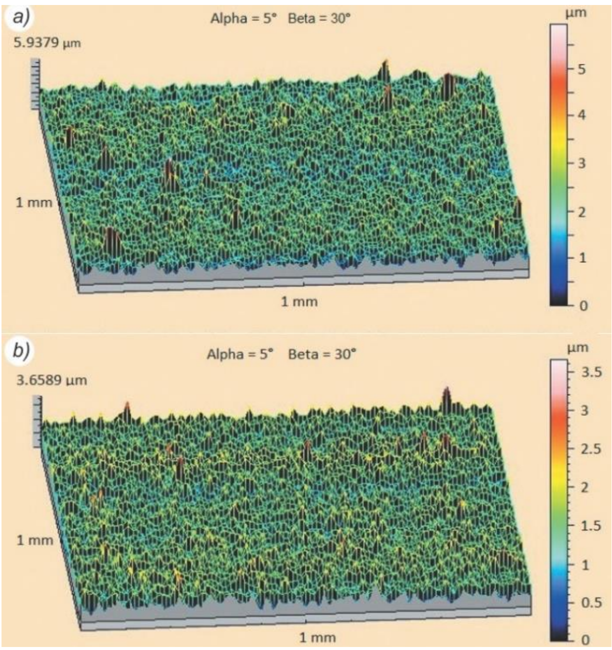

Fig. 6. Surface stereometric image: *a*) after machining using electrode ⌀0.25 mm, *b*) after machining using electrode ⌀0.15 mm

The coefficient of asymmetry for the surface after machining using electrode of ⌀0.15 mm was *Ssk* = 0.38298, while for the electrode ⌀0.25 mm it was *Ssk* = 0.59217. The lower the value of *Ssk* parameter, the more flattened the surface is, and the vertices of the slopes are rounded [10]. Positive value indicates sharpened vertices of surface, which, from the point of view of working of the surfaces of the elements, is unfavorable.

The kurtosis of the surface after machining using electrode with ⌀0.15 mm was *Sku* = 3.757 and for ⌀0.25 mm *Sku* = 5.0657. The value of *Sku* close to 3 indicates the distribution of ordinates of the studied surfaces near the normal distribution (uniform distribution of hills and valleys) [10]. Both samples were characterized by low values of mean square deviation of the surface roughness from the reference plane, respectively: *Sq* = 0.37676 µm for the surface after electrode treatment with ⌀0.15 mm and *Sq* = 0.4894 µm for ⌀0.25 mm.

Conclusions

Application of a wire electrode with a diameter of ⌀0.15 mm allowed for lower values of shape and surface roughness deviations as compared to machining using electrode with a diameter of ⌀0.25 mm. Significant impact on the values of deviations and surface roughness had a machining technology with electrode of ⌀0.15 mm, with an additional smoothing pass, as compared to the electrode of ⌀0.25 mm. The total machining time for the electrode ⌀0.15 mm was 160 min and in the case of ⌀0.25 mm, it was 118.5 min. Analysis of the results for use in the machining of the blade root of aircraft engines allows to discover a significant difference in the deviation of the direction of wire rewind. This is due to lower current values during discharge, lower discharge voltage, and lower feedrate. Further studies should aim at increasing the machining efficiency and the possibility of using a wire electrode with a diameter of less than 0.15 mm.

REFERENCES

1. Dąbrowski L., Oniszczuk D., Zawora J., Marczak M. „Wpływ parametrów hydromechanicznych w procesie wycinania elektroerozyjnego na efekty obróbki". *Inżynieria Maszyn*. 16, 3 (2011): pages 104–111.
2. Sharma P., Chakradhar D., Narendranath S. "Effect of wire material on productivity and surface integrity of WEDM-processed Inconel 706 for aircraft application". *Journal of Materials Engineering and Performance*. 25, 9 (2016): pages 3672–3681.
3. Klocke F., Vogtel P., Gierlings S., Lung D., Veselovac D. "Broaching of Inconel 718 with cemented carbide". *German Academic Society for Production Engineering (WGP)*. 7 (2013): pages 593–600.
4. Klocke F., Welling D., Klink A., Perez R. "Quality assessment through in-process monitoring of wire-EDM for fir tree slot production". *Procedia CRIP*. 24 (2014): pages 97–102.
5. Sharma P., Chakradhar D., Narendranath S. "Evaluation of WEDM performance characteristics of Inconel 706 for urbine disk application". *Materials and Design*. 88 (2015): pages 558–566.
6. Klocke F., Welling D., Klink A., Veselovac D., Nöthe T., Perez R. "Evaluation of advanced wire-EDM capabilities for the manufacture of fir tree slots in Inconel 718". *Procedia CRIP*. 14 (2014): pages 430–435.
7. Oniszczuk-Świercz D., Świercz R., Dąbrowski L., Marczak M. „Konstytuowanie warstwy wierzchniej Inconelu 718 po wycinaniu elektroerozyjnym". *Mechanik*. 4 (2015): pages 71–74.
8. Mitsubishi Electric Corporation. "Wire-Cut EDM Systems, FA-S Advance Series machining characteristics data book". BQN-W-70538C, version 3.0, 2010.
9. Oniszczuk-Świercz D., Świercz R. „Obróbka elektroerozyjna – badanie impulsów elektrycznych napięcia i natężenia prądu". *Mechanik*. 2 (2017): pages 112–113.
10. Niemczewska-Wójcik M. „Struktura geometryczna powierzchni ukonstytuowana w procesie obróbki elektroerozyjnej". *Tribologia*. 5 (2010): pages 63–74.