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Investigation of the Effects of Processing Parameters on Measuring Accuracy in Electrical Discharge Machining of Ti-6Al-4V Alloy

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Abstract

Titanium alloys are one of the materials that are difficult to process due to their high strength, high hardness and low thermal conductivity, wherefore low tool life and surface quality and high energy consumption are involved in shaping them with traditional manufacturing methods. In particular, special tool geometries are required for the machining of complex geometry parts including helical groove, keyseat, micro-holes, etc. with traditional manufacturing methods, which leads to increases in machining costs. In such cases, non-traditional alternative processing methods are preferred. In this study, keyseat shaping procedures were performed according to DIN 6885 standard in the electro (die-sinking) erosion machine for Ti-4Al-6V alloy. As a result of experiments conducted in copper electrode and Belone EDM F dielectric fluid environment, the effects of different processing parameters (discharge current, pulse on time and pulse off time) on measuring accuracy were investigated. In addition, the effects of 3D surface and SEM images and processing parameters on the accuracy of the coordinate measurement were evaluated. With the low discharge current, less thermal energy is transferred to the workpiece and smaller particles are removed from the workpiece, obtained in closer results to the targeted values. The biggest difference between the targeted keyseat depth, width and length and the measured value was 18.13%, 4.24% and 0.625%, respectively. The results closest to the specified standard keyseat dimensions were obtained in Ip=9A, Ton=150µs, Toff=120µs processing parameters.

1. INTRODUCTION

Key and keyseat are widely used in power transfer operations. It is very important that it is done with the characteristics and precision to withstand the forces formed during the power transfer [5-6]. The dimensions of the keyseat are determined according to the diameter of the shaft. If the keyseat is not made within the intended dimensions, it can cause serious problems. Therefore, it is important that the keyseat is produced within the intended size limits and from high strength material. The fact that the machined parts will be used in important places such as movement and power transmission by working at high temperature and speed increases the importance of processing parameters even more. In this context, in the studies on the processing of titanium alloy with the EDM method, Verma et al. investigated the effects of different machining parameters by die-sinking electro-erosion on the machining of titanium alloy using copper electrodes. In the experiments, they used to pulse on time, pulse off time, dielectric pressure, and voltage parameters as processing parameters. In their studies, they achieved higher material removal rate in the use of high voltage, high pulse on time and medium dielectric pressure. Increasing the pulse on time caused an increase in microcracks on the machined surfaces. In addition, dielectric flow pressure has played an important role in increasing the material removal rate. They observed that when dielectric flow pressure was low, it was inadequate to remove debris [7]. Klocke et al. [8] compared the effect of polarity in processing Ti-6Al-4V titanium and 42CrMo4 iron alloy with die-sinking electro erosion. Bhaumik et al. [9] The effect of titanium G6 alloy on the material removal rate (MRR) and tool wear rate (TWR) of different tool materials such as copper, brass, and zinc during EDM performance they have evaluated. They obtained higher MRR with brass and zinc tools than copper team. However, copper electrode performed better in tool wear. Singh et al. [10] have attempted different flushing methods to improve the flushing

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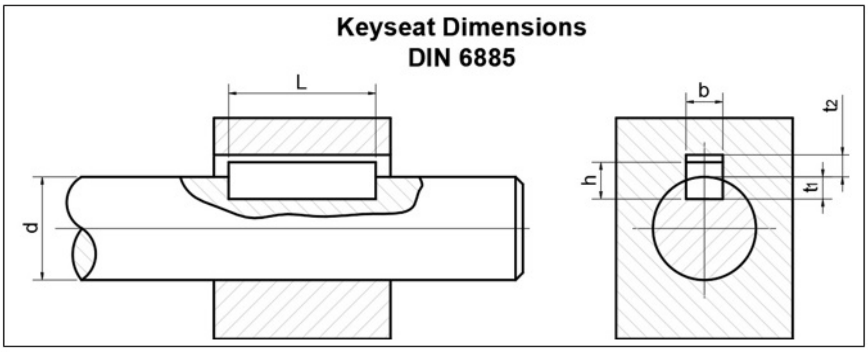
action during EDM. They used copper tools with and without holes. They observed that flushing using compressed argon gas from perforated tools had a positive effect on MRR and TWR throughout. Prakash et al. [11] investigated the dimensional accuracy of the processing depth by processing AISI 1035 material with EDM. In their study, they used discharge current, pulse on time and pulse off time as processing variables. Gambling et al. [12] investigated the surface integrity and dimensional accuracy of P91 steel in-EDM processing. Sanchez et al. [13] investigated the effects of the parameters used in the EDM method on dimensional accuracy and optimized the result. After the literature research, it was observed that there was no comprehensive study to machining keyseat in standard sizes determined by mile diameter with EDM.

In this study, electro-erosion machining experiments were carried out in different processing parameters in order to machining keyseat in DIN 6885 standard for Ti-6Al-4V alloy with cylindrical geometry. As a result of the experiments, keyseat dimensions were measured with CMM device. In addition, the effects of 3D surface and SEM images and processing parameters on the accuracy of the measurement were analyzed.

2.MATERIALS AND METHODS

2.1. Experimental Equipment

The main purpose of this study is to determine the effects of processing parameters on the completeness of the measurement in the process of machining the keyseat with EDM to the Ti-6Al-4V alloy. In this study, Ti-4Al-6V titanium alloy with a diameter of 14 mm was used as the workpiece material. For the specified diameter, the DIN 6885 standard is set to be keyseat dimensions width (b) 5mm, depth (h) 5mm, keyseat depth (t1) 3mm and length (L) 20mm. Keyseat sizes according to DIN 6885 standard are given in Figure 1.



in accordance to DIN 6885					
Diameter	**Width**	**Depth**	**Shaft Keyseat Depth**	**Hub Keyseat Depth**	**Keyseat Length**
d (Min.-Max.)	**b**	**h**	**t_1**	**t_2**	**L** (Min.-Max.)
	mm	**mm**	**mm**	**mm**	**mm**
12-17	5	5	3	d+2.3	10-56

Figure 1. *Keyseat dimensions according to DIN 6885 standard*

Copper material with 99.5% purity was preferred as a tool (electrode). The tools were prepared by cutting on a wire erosion bench based on the keyseat dimensions. In Figure 2, the dimensions of the workpiece and tool, and the processing principle are shown. The experiments were carried out on the Furkan compact 1 Z-NC type die-sinking electro erosion bench. Belone EDM F liquid with high flash point and low viscosity was used as dielectric fluid.

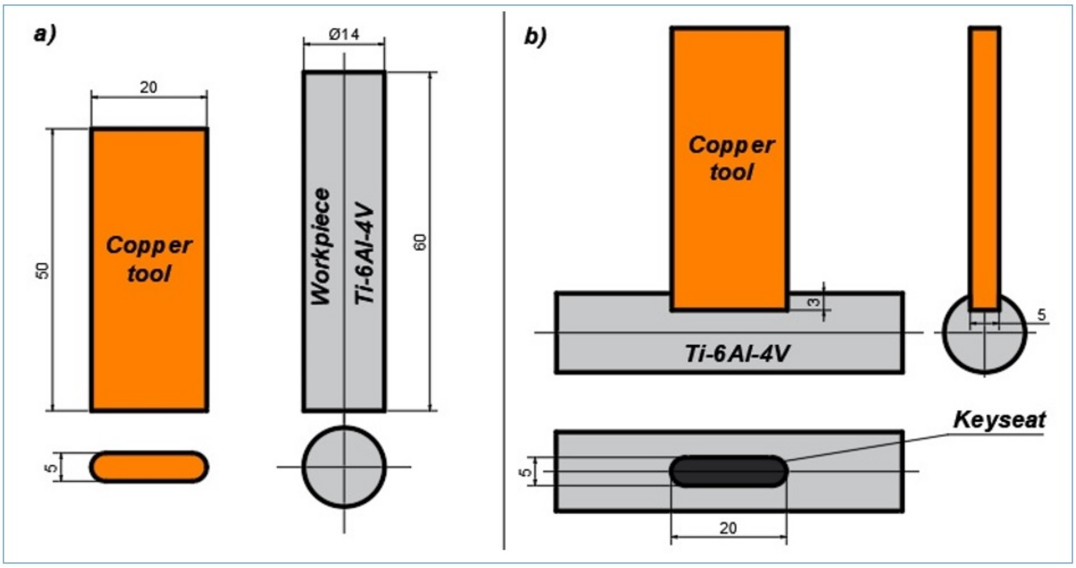


Figure 2. *a) Dimensions of the workpiece and tool (electrode), b) processing principle and keyseat dimensions*

2.2. Experimental design

As a result of preliminary experiments and literature review, three different discharge currents (Ip), three different pulse on times (Ton) and two different pulse off times (Toff) were determined as variable parameters. Table 1 shows the levels of variable processing parameters and the parameters kept fixed.

Table 1. *Processing parameters*

Processing Parameters	Levels		
Variable parameters	1	2	3
Discharge current, A	9	12.5	15
Pulse on time, µs	150	200	250
Pulse off time, µs	100	120	---
Fixed parameters			
Dielectric pressure, kgf/cm2	0.4		
Retract distance, mm	4.5		
Workpiece material	Ti-6Al-4V		
Workpiece polarity	Negative		
Tool (Electrode) material	Copper		
Tool polarity	Positive		
Dielectric fluid	BELONE EDM F		

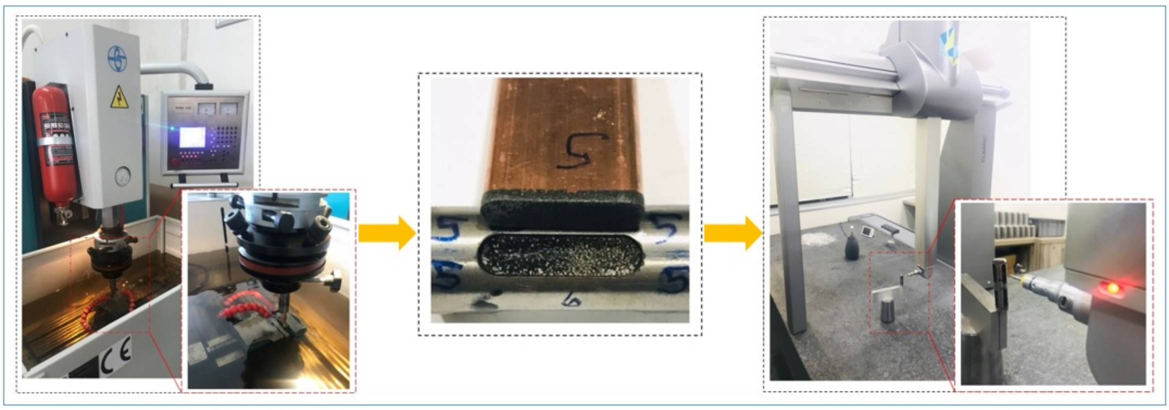


Figure 3. *Experimental setup and workflow*

Dimensional measurements of keyseats obtained after the experiments were made with Global Classic 091508 model coordinate measuring machine (CMM). Before the measurements, the calibration process was performed at the angle of A90B-90. The plane formed from the ground surface of the workpiece was leveled and the position of the workpiece was fixed by verifying with the "line" formed from one side of the keyseat. “t1” measurement results were obtained by calculating the plane on the ground and the extreme point of the outer diameter. The "b" measurement results were obtained with the lines obtained by contacting two points on the side surfaces of the keyseat. Radius (R) measurements were obtained with circles created by touching three points, and the distance measurement between the circles and the "L" dimension were checked. Perpendicular to the ground "line" was formed from the side walls of the keyseat, and perpendicularity checks were made with the plane on the floor. All calibration and measurement processes were carried out at 21℃. The experimental setup and workflow are shown in Figure 3.

3.RESULTS

In this study, experiments were carried out according to the Taguchi L_{18} experimental design, which was created according to different machining parameters for keyseat machining in DIN 6885 standard on Ti-6Al-4V alloy by EDM method. As a result of the experiments, dimensional measurements of the keyseat were made and the results are given in Table 2.

Table 2. *Experimental design*

Experiment No.	Discharge current I_p	Pulse on time T_{on}	Pulse off time T_{off}	Depth t_1	Width b	Length L	Radus r_{avg}
1.	9	150	100	2.952	5.153	20.075	2. 5680
2.	9	200	100	2.946	5.191	20.124	2. 5800
3.	9	250	100	2.704	5.212	20.117	2. 5810
4.	12.5	150	100	2.459	5.150	20.066	2. 5670
5.	12.5	200	100	2.851	5.167	20.112	2. 5805
6.	12.5	250	100	2.914	5.169	20.100	2. 6205
7.	15	150	100	2.570	5.132	20.092	2. 5590
8.	15	200	100	2.597	5.173	20.118	2. 5620
9.	15	250	100	2.891	5.202	20.125	2. 5865
10.	9	150	120	3.014	5.042	20.080	2. 5780
11.	9	200	120	2.950	5.166	20.094	2. 5945
12.	9	250	120	2.890	5.175	20.118	2. 6070
13.	12.5	150	120	2.700	5.161	20.094	2. 5675
14.	12.5	200	120	2.830	5.182	20.105	2. 5650
15.	12.5	250	120	2.872	5.184	20.125	2. 5815
16.	15	150	120	2.456	5.161	20.079	2. 5640
17.	15	200	120	2.763	5.145	20.070	2. 6065
18.	15	250	120	2.695	5.182	20.097	2. 5900

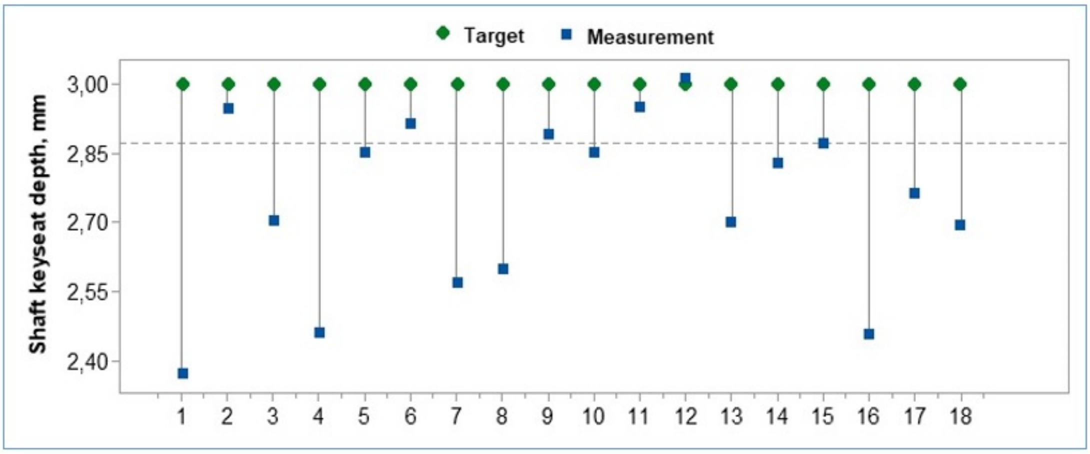


Figure 4. *Keyseat depth*

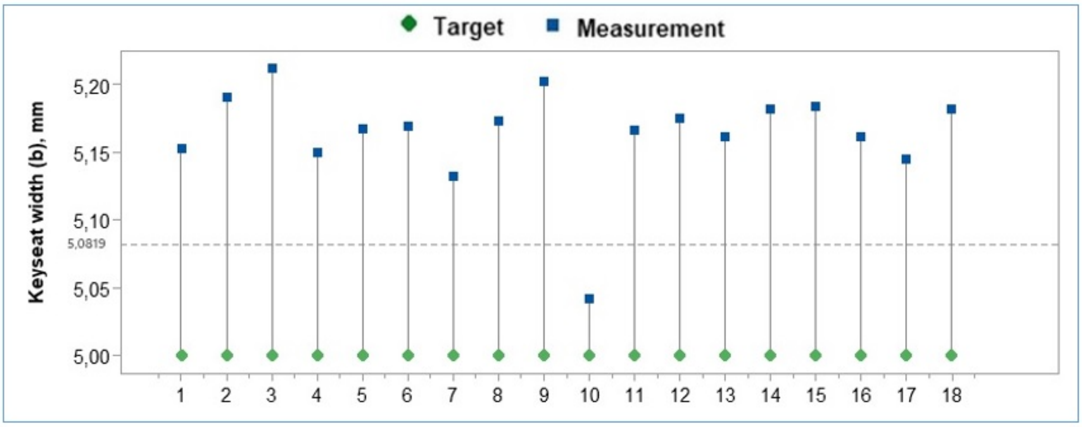


Figure 5. *Keyseat width*

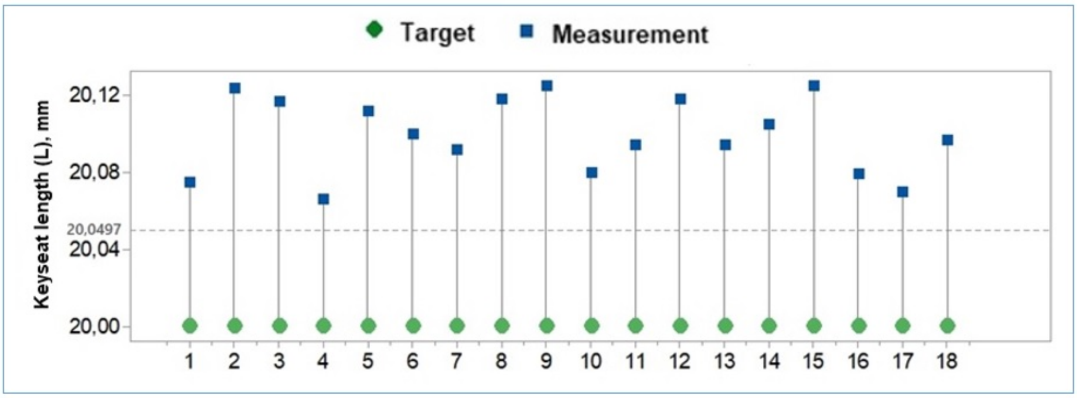


Figure 6. *Keyseat length*

Figure 4-6 shows the graphs created according to the keyseat values obtained as a result of machining Ti-6Al-4V alloy with different machining parameters. When Figure 4 is examined, the closest value to the targeted keyseat depth was obtained in experiment no. 10 (Ip=9A, Ton=150µs, Toff=120µs). The difference between the average keyseat depth of 3.014 mm and the keyseat depth obtained as a result of this experiment was calculated as 4.10%. The biggest difference between the target value and the measured values was 18.13% in the test condition no. 4. It is thought that these changes in depth are caused by the machining process and tool wear depending on the machining parameters. When the discharge current and the pulse on time are high, the chip removal rate increases, but the high temperature caused causes faster tool wear

[14]. On the other hand, it can be said that the sticking of chips from the machined material to the tool causes irregularity in arc formation, reducing the chip removal rate and thus moving away from the target value in depth. As a matter of fact, the deviation is higher due to the reasons mentioned in the experiments where the discharge current and pulse duration are high (Table 2).

Figure 5 and Figure 6 show the changes in keyseat width and length, respectively, according to the machining parameters. The average of the keyseat width and length values are 5.0819 and 20.0497, respectively. The largest difference between the targeted keyseat width and the measured value was 4.24%, while the deviation between the keyseat length was 0.625% at most. These values indicate that the deviation in keyseat width is larger. This result is mainly due to the large surface area falling on the keyseat width and thus the formation of chips and sparks on the larger surface. On the other hand, it is thought that the increasing arc gap [15] with the increase of thermal energy in experiments with high pulse duration causes an increase in the amount of deviation from the target value. However, less thermal energy is transferred to the workpiece with a low discharge current and chip removal in smaller particles from the workpiece resulted in closer results to the targeted values (Table 2). In addition, the low pulse on time and high pulse off time reduced the rate of spark falling on the workpiece surface per unit time [16]. Thus, less melting and evaporation processes, less pits and less crater formations increased the accuracy of measurement.

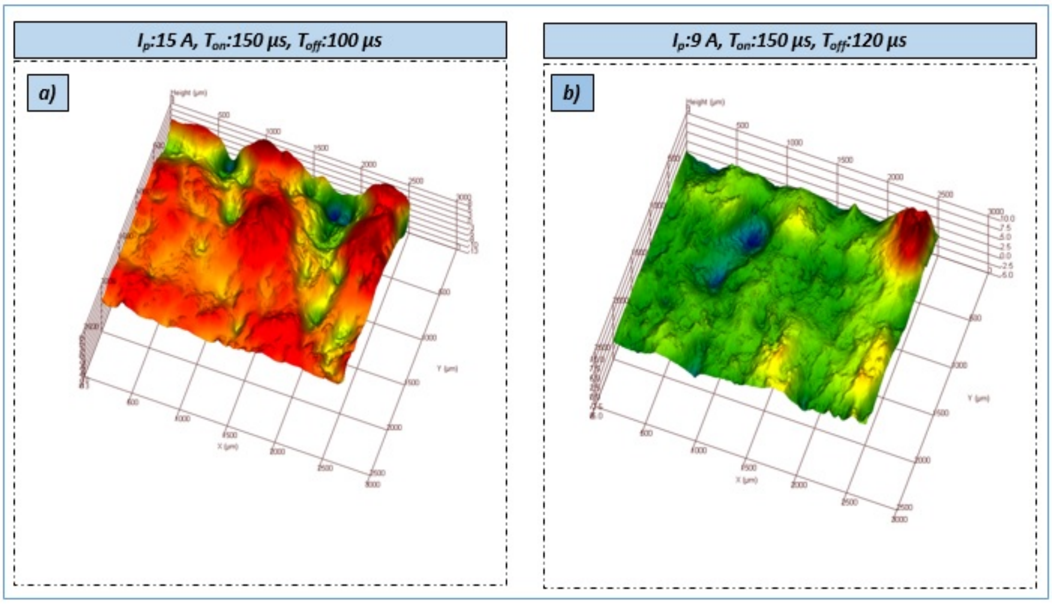


Figure 7. *3D topographies of processed surfaces*

Figure 7 shows the 3D surface topographies taken from the base of the keyseat. Considering that the pulse on time (Ton) remains the same, the formation of irregular structures consisting of high peaks and valleys on the machined surface in Figure 7a draws attention, while in Figure 7b it is seen that the machined surface has a relatively more homogeneous structure. High Ip and low Toff values caused deterioration of the homogeneous structure on the surface and had a negative effect on both surface roughness and measurement accuracy. By increasing the impact dwell time, that is, when the metal removal rate is reduced, shallower craters were formed on the workpiece surface [17]. In order to examine these formations more clearly, SEM images were taken from the machined keyseats for the same machining conditions (Figure 8).

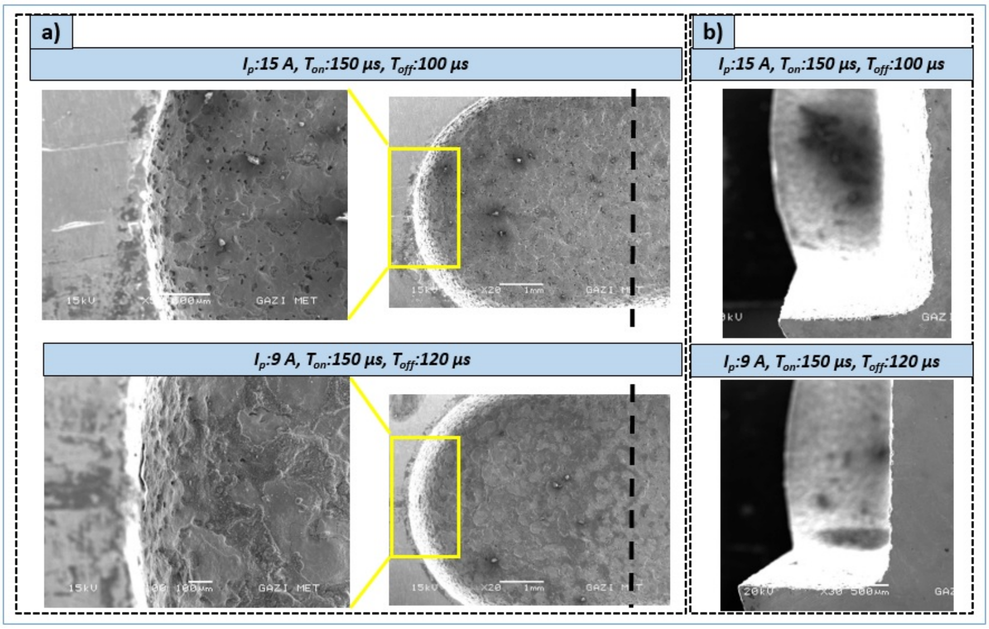


Figure 8. *SEM images of corner radius and cross section*

It is very important to clean the residues in the processing area accurately and quickly in reducing the amount of error in the geometric dimensions of the machined surfaces. Removal of debris from the keyseat cavity is necessary to achieve stable machining performance. If residues cannot be removed from the machined area, it can lead to unstable machining performance and poor geometric dimensions [18–20]. The desired edge radius depending on the machining geometry and the SEM images obtained after metallographic polishing on the cross-section of the processed samples are given in Figure 8. It is seen that the craters and keyseat profile lines on the machined surfaces change depending on the machining parameters. As can be seen from the cross-section pictures (Figure 8b), deeper and wider craters due to machining parameters that provide high metal removal rate increased the deviation from the dimensions. At the same time, sparks will occur on the larger surface, as possible adhesions on the tool surface disrupt the tool geometry [21]. It is thought that this process enlarges the removed surface area, causing both deviations from the keyseat profile and an irregular form of surface quality.

In the light of all the results, it has been observed that in the machining of parts with complex geometry by electro-erosion, deviations may occur in different sizes due to arc formation according to the profile-tool surface area. It has been revealed that the most important parameters affecting the material removal rate and surface integrity in EDM of Ti-6Al-4V alloy are flow and pulse on time. On the other hand, the fact that no residues stick to the machined surfaces indicates that the dielectric fluid and application pressure used in the experiments were chosen correctly. When electro-erosion machining is required on parts produced from Ti-6Al-4V alloys, it is recommended to use low current, medium pulse on time and high pulse off time in order to achieve the desired dimensions and surface qualities.

4.CONCLUSIONS

In this study, a comprehensive evaluation of the dimensional measurement results obtained as a result of keyseat forming into Ti-4Al-6V alloy with different machining parameters in EDM was made. The findings obtained as a result of the study are presented below:

- By transferring less thermal energy to the workpiece with low discharge current and removing chips from the workpiece in smaller particles, results closer to the targeted values were obtained.

- High Ip and Ton and low Toff values caused deterioration of the homogeneous structure on the machined surface and had a negative effect on the measurement accuracy.

- Optimum parameters were obtained as Ip=9A, Ton=150µs, Toff=120µs for keyseat cutting into Ti-4Al-6V alloy. In this context, the closest keyseat depth to the target value was measured as 3.014 mm.

- The largest deviations between the targeted keyseat depth, width and length and measured values were 18.13%, 4.24% and 0.625%, respectively.

- It has been observed that correct and rapid cleaning of the residues in the processing area is an important factor in reducing the amount of errors in the geometric dimensions of the surfaces processed by electro-erosion.

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