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EXPERIMENTAL INVESTIGATION OF RECAST LAYER FORMATION ON THE SURFACE OF Ti-6Al-4V TITANIUM ALLOY DURING EDM PROCESS (machining carried out at lower range of machining parameters)

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A b s t r a c t

The recast layer forms during the machining of Ti-6Al-4V titanium alloy carried out with a use of electrical discharge machining (EDM). The paper presents the description of EDM process carried out at lower range of machining parameters also the formation process of recast layer. The recast layer was analyzed using scanning electron microscopy and 3D viewer image. The performed experiments involved application of copper and graphite electrode with positive polarity. In order to analyze the results, the authors used design of experiment (DOE) method – Taguchi technique (L18) with mixed-level design. The influence of peak current (A), servo voltage (V), pulse on time (Ton) and pulse off time (Toff) on the recast layer was described in the article.

Keywords: EDM, Ti-6Al-4V titanium alloy, SEM, recast layer

Badania wpływu parametrów procesu cięcia elektroerozyjnego na warstwę przetopioną stopu Ti-6Al-4V (przy zastosowaniu małych wartości wyładowań elektrycznych)

S t r e s z c z e n i e

W artykule przedstawiono wyniki badań mikrostruktury warstwy przetopionej stopu tytanu Ti-6Al-4V w wyniku cięcia elektroerozyjnego (EDM), w zakresie małych wartości wyładowań elektrycznych z zastosowaniem miedzianej i grafitowej elektrody spolaryzowanej dodatnio. Dokonano analizy badań mikroskopowych przeprowadzonych z użyciem skaningowego mikroskopu elektronowego SEM, stosując zaawansowaną metodę DOE (ang. DOE – Design Of Experiments) wyznaczania wpływu zmiennych wejściowych na wynik analizowanego procesu. Wyznaczono wpływ parametrów prądowych – napięcia, czasu włączenia i wyłączenia układu na jakość warstwy przetopionej stopu tytanu.

Słowa kluczowe: EDM, stop tytanu Ti-6Al-4V, SEM, warstwa przetopiona

1. Introduction

Electric discharge machining (EDM) is a non-traditional precision processing which involves electrical spark erosion process between the electrode

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and the specimen immersed in a dielectric fluid. The spark-erosion manufacturing is an important machining technioque which allows to process hardly cuttable mould material with curved surfaces or sharp angles and achieve workpiece with required geometry. The EDM process provides enhanced productivity, accuracy and better surface characteristics. This method has been widely used in the modern metal industry for manufacturing complex cavities in moulds and dies, which are difficult to obtain by conventional machining methods [1].

During the EDM process the estimated discharge point temperature is thousand degrees (°C) in order to rapidly achieve machined material at the charge point. The locally generated high-temperature sparks result in rapid evaporation of the surrounding dielectric fluid and expansion of its volume. Part of molten material is quickly removed from the surface of machined workpiece. The remaining molten material rapidly resolidifies on the machined surface and form so called recast layer with different microstructural and metallographic characteristics than the base material [2]. The recast layer is typically very fine-grained, hard and may be alloyed with carbon due to material transfer from the tool [3].

This paper describes the formation process of resolidified layer which is present during the EDM process of Ti-6Al-4V titanium alloy (Table 1) performed using copper and graphite electrode with positive polarity.

Table 1. Chemical composition of Ti-6Al-4V alloy

C	Fe	N2	O2	Al	V	H2	Ti
0.08	0.25	0.05	0.2	5.5-6.7	3.5-4.5	0.0125	Balance

2. Experimental Setup

The drilling processes were performed on Joemars AZ50R EDM. Peak current (*Ip*), pulse on time (T_{on}), pulse off time (T_{off}) and voltage (*V*) were considered to ascertain their effect on recast layer. The pulse on time (T_{on}) is defined as the duration of current flow in one cycle, while the “pulse off” time (T_{off}) is the time gap between two consecutive sparks. Servo voltage (*V*) specifies a reference voltage for servo motions to keep gap voltage constant.

The statistical analysis was based on L18 mixed-level design. The L18 array has four columns and eighteen rows with three levels. Four machining parameters were assigned to the columns. The rows correspond to eighteen experiments with various combination of machining parameters values (Fig. 1 and Table 2).

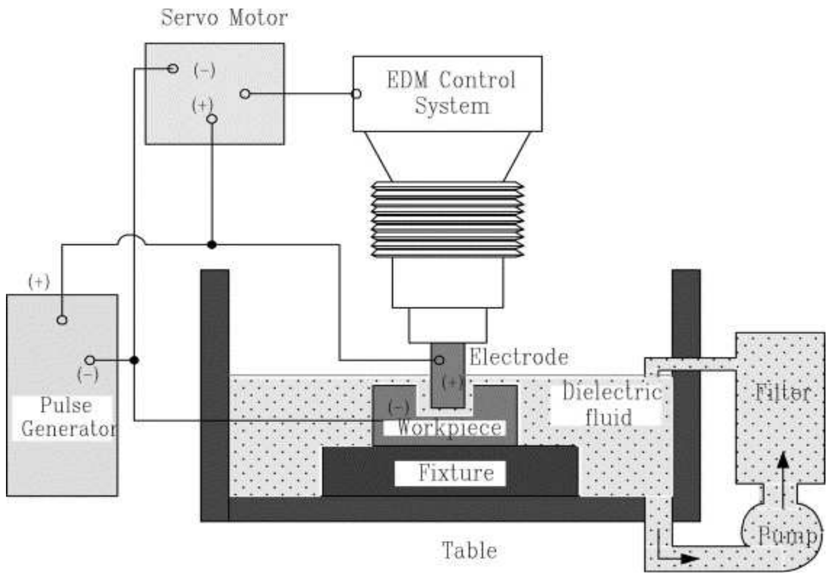


Fig. 1. Schematic diagram of experimental setup

Table 2. Experimental Setup

Parameter	**Description**
Work piece material	Ti-6Al-4V (Grade-5)
Work piece size	50× 60 × 5 mm
Electrode material	Copper and Graphite
Electrode diameter	10 mm
Electrode polarity (P)	Positive
Dielectric fluid	Commercial Kerosene
Flushing pressure	3.5 kgf/cm^2
Voltage, V	170, 205 V
Peak current Ip, A	9,17,21
Pulse on time T_{on}, µs	49,100, 145
Pulse off time T_{off}, µs	52,40,24

Peak current (Ip) is the maximum value of current during spark. If the value of gap voltage is higher than servo voltage, the electrode advances for machining. Otherwise the electrode retracts to open the gap. The Ti-6Al-4V titanium alloy was machined with copper and graphite tool electrode with positive polarity. Commercial kerosene was used as dielectric fluid.

3. Results and Discussion

3.1. Scanning Electron Microscopy (SEM)

Scanning electron microscopy is widely used to generate high-resolution images of specimens and analyze spatial variations in chemical composition. A solidified layer couldn't be observed on SEM images. The images were obtained on JEOL JSM-5610 LV, with 100 µm image resolution.

Figure 2 show the results of SEM observations of samples obtained during EDM process performed with copper electrode. Black colored structure is the electrode material deposited onto the workpiece material. Figure 2a presents the SEM image of sample machined at lower voltage, lower peak current and lower spark gap. It can be concluded that operation at current value of 9A provides good surface. Carbide deposits can be observed on the surface. SEM image in Fig. 2b presents the surface of sample processed at lower voltage, medium peak current and spark gap. It can be observed that surface roughness decreases and spherical shaped carbide deposits grow as the current increase from 9A to 17A. Also deeper pits can be observed. Figure 2c refers to workpiece machined at higher voltage and peak current value. The highest surface roughness was obtained for current value of 21A. It can be also concluded that carbide deposits and pits grow with the increase of current value.

a) b) c)

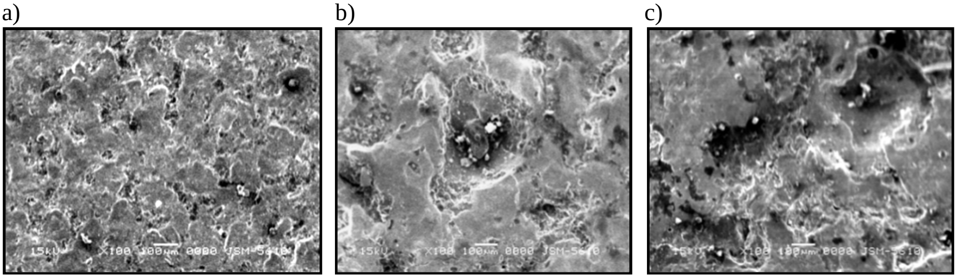


Fig. 2. SEM images of Ti-6Al-4V titanium alloy machined during EDM process with a use of copper electrode: a) V-50, A-9, T_{on} – 49, T_{off} – 52, b) V-50, A-17, T_{on} – 145, T_{off} – 24, c) V-62, A-21, T_{on} – 145, T_{off} – 24

Figure 3 shows the results of SEM images of samples submitted to EDM process performed using graphite electrode. Figure 3a shows the image of sample machined at lower values of voltage, peak current and spark gap. Low surface roughness and carbide deposition can be observed on the workpiece for current value of 9A. Small pits are visible on the surface. Figure 3b present the SEM image of workpiece processed at higher values of voltage, peak current and spark gap. It can be concluded that with the increase of current value from 9A to 21A the surface roughness rises, also pits depth and spherical carbide deposits grow. Figure 3c shows SEM image of specimen machined at higher voltage, low peak current and high spark gap. It can be observed that this process provides good surface. Depth of pits and carbide deposition is relatively lower.

a) b) c)

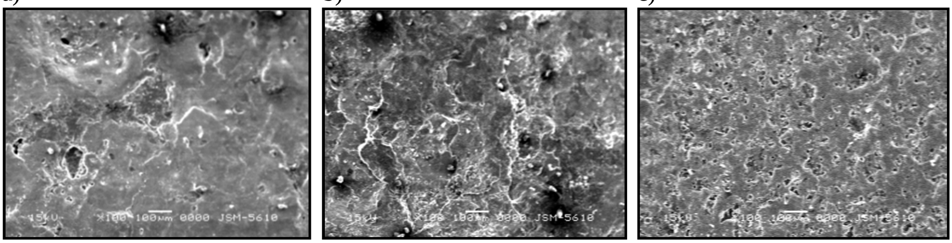


Fig. 3. SEM images of Ti-6Al-4V titanium alloy machined during EDM process with a use of graphite electrode: a) V-50, A-9, T_{on} – 49, T_{off} – 52, b) V-50, A-21, T_{on} – 145, T_{off} – 24, c) V-62, A-9, T_{on} – 145, T_{off} – 24

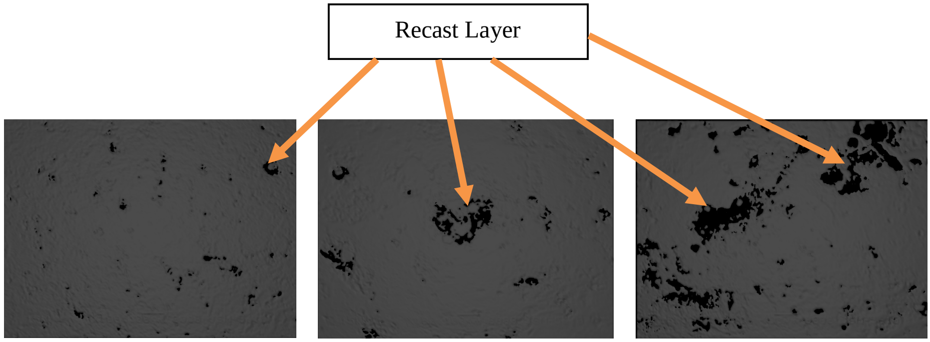
3.2. Recast Layer

The EDM proces removes material and involves melting process at high temperature. Due to the repeated heating and cooling cycle of the electrolyte a heat affeacted zone (HAZ) is formed below the recast layer. HAZ area is affected by the conduction of heat from the surface, which is melted by plasma sparks during active cycles [3].

Figure 4 shows the 3D viewer image generated from SEM image of recast layer formed during the EDM process carried out with a use of copper electrode. Poor surface quality with uneven thickness distribution of recast layer can be observed. The presence of recast layer depends on two main factors, the tool material, machining polarity. Others machining parameters such as voltage and current affect the recast layer as well.

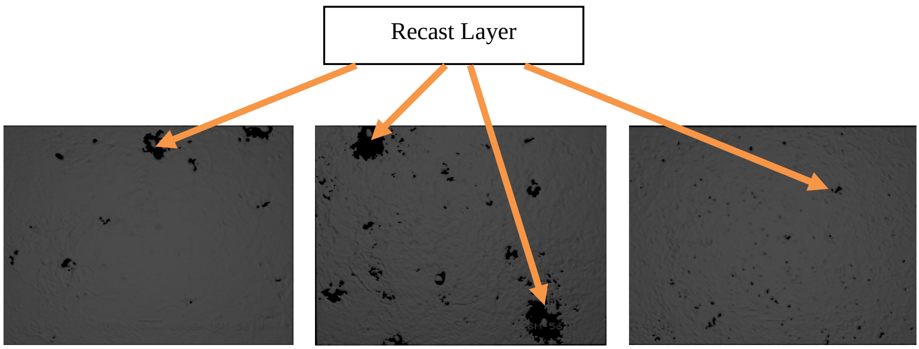
The black coloured structure is the recast layer formed during the EDM process. For EDM process carried out with a use of copper electrode with positive ploarity a thick recast layer formed if voltage and current incresed. The thinner recast layer was created for lower voltage and current values.

Figure 5 shows 3D viewer image generated from SEM image of recast layer created during the EDM process carried out with a use of graphite electrode with positive ploarity. A thick recast layer formed for lower values of voltage and current. Thinner recast layer was created during high voltage- and high current process. All 3D viwer images were genrated using ImageJ software.



a) b) c)

Fig. 4. 3D viewer image of recast layer: a) V-50, A-9, T_{on} – 49, T_{off} – 52, b) V-50, A-17, T_{on} – 145, T_{off} – 24, c) V-62, A-21, T_{on} – 145, T_{off} – 24



a) b) c)

Fig. 5. 3D viewer image of recast layer: a) V-50, A-9, T_{on} – 49, T_{off} – 52, b) V-50, A-21, T_{on} – 145, T_{off} – 24, c) V-62, A-9, T_{on} – 145, T_{off} – 24

Conclusion

The course of formation process of recast layer depends on type of material and machining polarity. Ti-6Al-4V titanium alloy is characterized by higher surface roughness and thinner recast layer formed during lower voltage and peak current, when copper as electrode material was applied. The opposite results were found for graphite electrode .

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Abbrivation

V – Voltage
A – Peak current
T_{on} – pulse on time
T_{off} – pulse off time
EDMing – EDM Machining
EDMed – EDM Machined

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