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Optimal set-up and surface finish characteristics in electrical discharge machining on Ti-5Al-2.5Sn using graphite☆

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Summary In electrical discharge machining (EDM) process which is an advance and non-conventional technique, the selection of machining parameters for achieving high machining performance is an important; however, very problematic task. In the current manuscript it was aimed to ascertain optimal machining set-up of EDM process related with fine surface finish. The die-sinking EDM was carried out using the both polarities (positive and negative) of graphite electrode. The microstructure of the workpiece surface was investigated by scanning electronic microscopy. The negative polarity produces, on average, nearly double surface roughness than that with positive polarity. The surface microstructure is deteriorated as the discharge energy level increases for both polarities.

Introduction

Titanium and titanium alloys are difficult-to-machine material for conventional machining techniques (Yilmaz and Okka, 2010; Pandey and Singh, 2010). On the other hand, electrical discharge machining is a non-conventional manufacturing process based on removing material from a part by means of a series of recurring electrical discharges between a tool called electrode and the workpiece part to be machined in the presence of a dielectric fluid (Rahman et al., 2011). EDM can machine effectively such type of hard material like titanium and its alloys that having high strength ratio (Rahman et al., 2010). In this non-conventional process, it is an important moreover, very problematic job to select the machining parameters for achieving high machining performance (Khan et al., 2011). Due to the complex and

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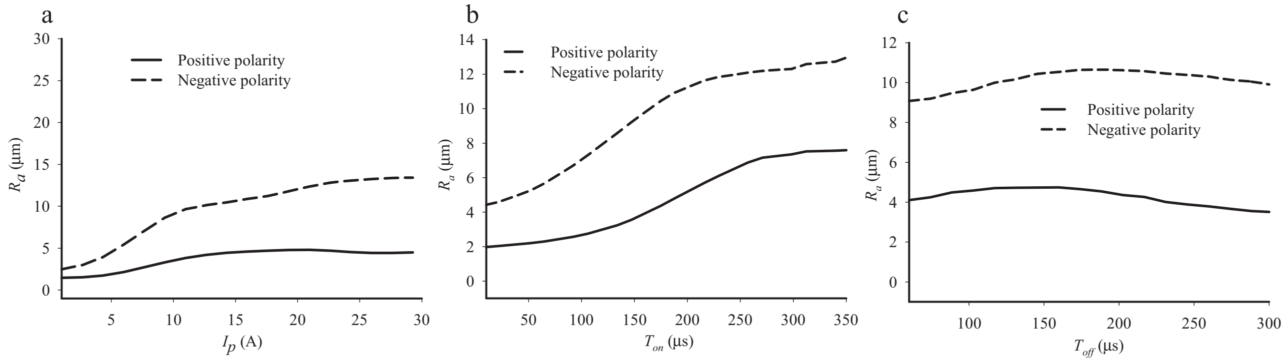

Figure 1 (a) R_a versus I_p; (b) R_a versus T_{on}; (c) R_a versus T_{on}.

non-linear relationship between the input process parameters and output performance parameters, it is quite difficult to develop an accurate process model and use it to select the optimum process parameters for EDM process (Joshi and Pande, 2011). Several studies have been carried out to predict the process response, surface finish that comprises surface roughness and surface texture pursuing optimal condition of process, as well as economic machining. Amorim and Weingaertner investigated surface texture plus surface roughness of the machined workpiece was accomplished in EDM on copper-beryllium ASTM C17200 alloy (Amorim and Weingaertner, 2004). Surface roughness and thickness of recast layer of the machined surface was investigated in order to verify the EDM performance of composite materials, AISI 1045 medium carbon steel (Tsai et al., 2003). The surface crack and average thickness of the recast layer was studied in commercially pure iron, steel and AISI 01 tool steel after EDM (Wong et al., 1995). EDM was performed on Ti-6Al-4V titanium alloy in order to determine the performance characteristic including surface roughness (Kao et al., 2010). Thus, it is evident that prior works are limited with specific work—tool material combination together with machining circumstances. Moreover, still there is lack of performance characteristics investigation in EDM on Ti-5Al-2.5Sn material using both polarities of graphite electrode. Therefore, the present work aimed to ascertain optimal machining settings of EDM process related with fine surface finish. Besides, the influences of parameters on surface finish characteristics and surface microstructure of Ti-5Al-2.5Sn material was studied.

Research methodology

The titanium alloy Ti-5Al-2.5Sn is available commercially in many forms. The workpiece material is titanium alloy Ti-5-2.5 and graphite is chosen as electrode materials for the present study. Both positive and negative polarity of graphite electrode was considered in this study. A number of experiments were carried out varying peak current, pulse-on time, pulse-off time, and polarity. For each experiment, a new tool and workpiece were used. Each experiment was conducted at a fixed supply voltage of 120 V and dielectric flushing pressure of 0.15 MPa. Surface roughness was measured to evaluate the quality of the machined surface. The effect of the process parameters on surface roughness are analysed utilising the experimental results. The data were further analysed for sensitivity to identify the influence of the varied input process parameters on output response, R_a. In this research, optimisation of the EDM process is concerned with producing a good surface finish. Therefore, the machining parameters that offer the optimal performance are detected from the trend of the graph. This is accomplished for surface roughness for positive and negative polarity of graphite. Finally, the surface topography of the EDM machined surface at various settings is analysed and illustrated using scanning electronic microscopy images.

Effect of process parameters

The effect of I_p, T_{on}, and T_{off} on R_a for different polarities of graphite electrode are shown in Fig. 1(a), (b) and (c) respectively. With positive graphite electrode a disparate characteristic of R_a is appeared with the increase of I_p. However, the R_a increases gradually as the I_p increases for negative polarity. Positive graphite electrode depicts an unstable machining. Thus, a disparate characteristic of R_a is appeared as I_p increases. It is seen that R_a increases when the T_{on} increases for both polarities. The fine surface finish is achieved at low T_{on}. The diverse impact of T_{off} on R_a characteristics is apparent in this study. It is explored that the R_a initially increases and then decreases with the increasing in T_{off} for both polarities. When the T_{off} is too short, there is not enough time to clear the disintegrated particles from the gap between the electrode and the workpiece. It is obvious that a uniform erosion of material from the workpiece surface is acquired while the T_{off} is long;

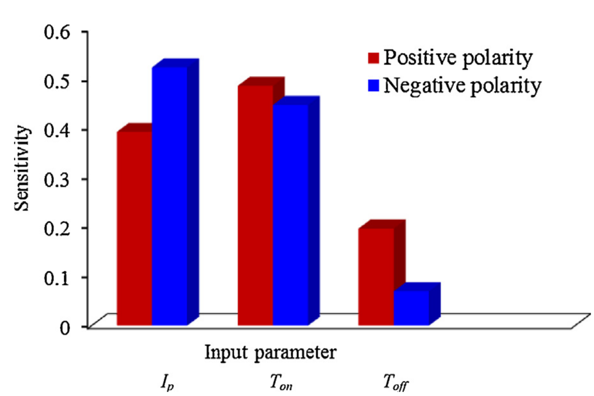

Figure 2 Sensitivity analysis for R_a.

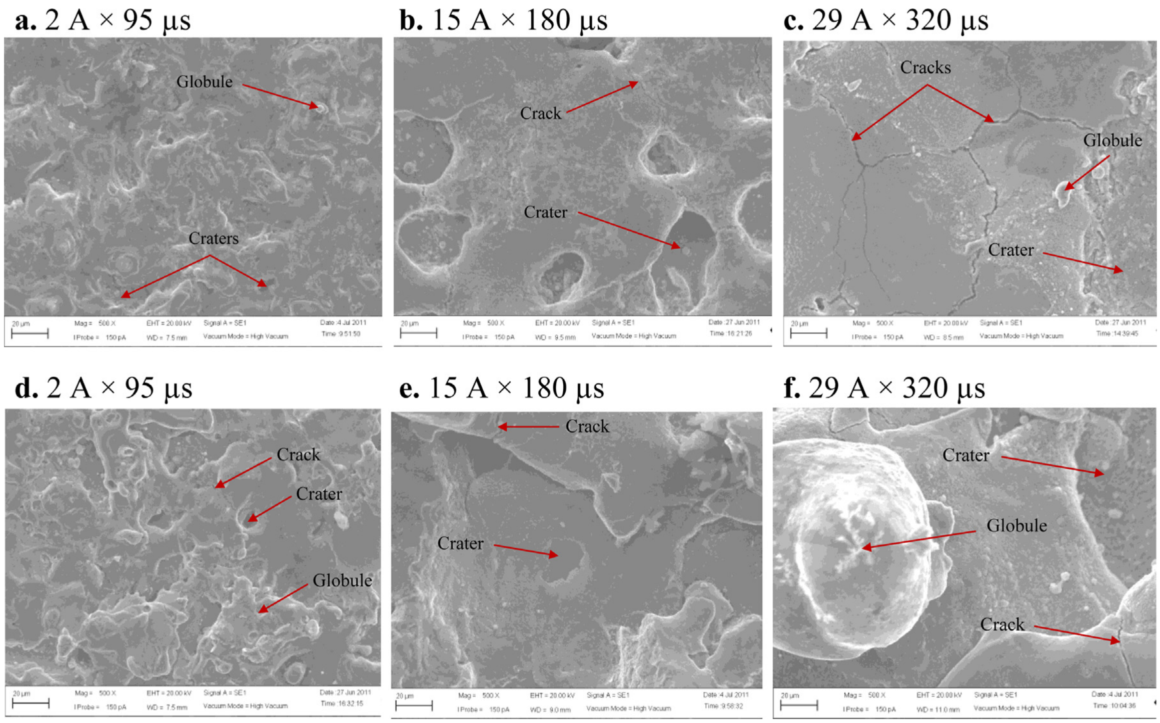

Figure 3 Microstructure of the surfaces (a)—(c) with +ve; and (d)—(f) with −ve polarity.

Table 1 Optimum settings of the machining parameters for R_a.

Positive polarity		Negative polarity	
Optimum setting	R_a (μm)	Optimum setting	R_a (μm)
$I_p = 1$ A	1.453	$I_p = 1$ A	2.490
$T_{on} = 10$ μs	1.975	$T_{on} = 10$ μs	4.420
$T_{off} = 300$ μs	3.502	$T_{off} = 60$ μs	9.077

otherwise, a non-uniform erosion of the workpiece surface will occur. Therefore, small range of T_{off} produces rough surface and long T_{off} produces fine surface. It is found that positive polarity offers better surface finish than that obtained with negative polarity due to thermo-physical properties of the electrode material. The negative polarity produces, on average, nearly double R_a than that of positive polarity. More stable machining of graphite electrode is found with negative polarity. The results obtained for sensitivity to identify the influence of the parameters on R_a are shown in Fig. 2. Results show that the T_{on} has the highest effect on R_a for a positive graphite electrode, while the I_p is the most important parameter for a negative graphite electrode. Pulse-off time affect the R_a after T_{on} and I_p for both polarities. The parameters that offer the optimal performance are found from the trend of graph and tabulated in Table 1.

Microstructure of the machined surface

The topography of the machined surface generated during EDM with graphite electrodes is illustrated in Fig. 3. It is evident that the machined surface is characterised by globules, craters, cracks, and small debris like pockmarks. The crater size depends on the pulse current as well as the discharge energy (Kathiresan and Sornakumar, 2010; Khan and Rahman, 2014). The size and depth of the discharge craters increase as the energy level increases for both polarities. It is explored that the number of globules decreases as the energy intensity increases. Besides, the depth and width of cracks increases as the discharge energy increases. The main factors that lead to a greater degree of crack formation is induced stress. Analysis reveals that the size of craters and number of globules are greater when the polarity is negative as compared to positive polarity. As a result, the surface obtained with negative polarity is rougher than that obtained with positive polarity. It is seen that positive polarity furnishes a higher degree of cracking, while negative polarity produces a larger number of craters at high discharge energy (29 A × 320 μs).

Conclusion

The optimum parameters for finest surface with positive polarity are 1 A I_p, 10 μs T_{on}, and 300 μs T_{off} whilst these with negative polarity are 1 A I_p, 10 μs T_{on}, and 60 μs T_{off}. Positive polarity results better surface finish than that obtained with negative polarity. The negative polarity produces nearly double R_a than that with positive polarity. The T_{on} has the highest effect on R_a for a positive graphite, while the I_p is the most important parameter for a negative graphite electrode. Low discharge energy produces a fine surface structure. The size of craters and number of globules are greater when the polarity is negative as compared to positive polarity. This approach will support the process in improvement the process productivity, finishing capability and economical operation of die-sinking EDM process.

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