International Journal of Engineering Inventions
e-ISSN: 2278-7461, p-ISSN: 2319-6491
Volume 13, Issue 3 [March. 2024] PP: 126-130

Analysis of Tool Wear Rate in EDM using Aluminum Electrode for Ti-6Al-4V

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Abstract: *The application of EDM is very popular for shaping products in the fields of molds, etc. Therefore, improving the machining efficiency of this technology is essential. In this study, the influence of process parameters in EDM was investigated. Taguchi and ANOVA were used to design the experiment and analyze the results. Process parameters (Voltage (Vg), Current (I) and Pulse on time (Ton)) and quality indicator (tool wear rate (TWR)) were selected for evaluation in the study. Ti-6Al-4V and Tungsten Carbide electrode Aluminum (Al) were used for the study.*
Keywords: *EDM, TWR, electrode, Ti-6Al-4V*

I. INTRODUCTION:

Titanium alloys are metals that contain a mixture of titanium and other chemical elements. These alloys have very high tensile strength and toughness (even at extreme temperatures). In general, non-conventional processes are influenced by two factors :(1) mechanism of interaction between the tool and the workpiece, and (2) media used to effect the transfer of energy from the tool to the workpiece. In contrast, conventional machining requires a direct mechanical contact between the tool and the workpiece, giving rise to undesirable properties in the workpiece due to residual, mechanical and thermal stresses. Thermally based energy transfer is the main material removal mechanism for several non-conventional machining processes, including electrical discharge machining (EDM), laser machining, electron beam machining, and plasma arc machining. Machining performance of Ti-6Al-4V using electric discharge machining process will be studied in present study. Therefore, research to clarify this field is very necessary.

Research results on EDM have shown that: Electrode wear were increased with the increase in both discharge current and pulse duration almost linearly due to the higher energy density. The crack and damage characteristics of machined surfaces were reduced by decreasing the discharge current and shortening the pulse duration. Investigated the influence of high spindle speeds on machining performance [1]. The experiments were performed to investigate electrode wear by varying SPR and Ton. Influence of the Process Parameters to Manufacture Micro cavities by Electro Discharge Machining (EDM) has [2]. Increasing demand on micro-product has driven the development of innovative manufacturing process to this new requirements as well as the adaptation of conventional metal cutting process to these micro-scale applications [3]. Two process parameters were used such that voltage and pulse on time to investigate surface topography of cavities. In EDM process, the performance was determined by Material Removal Rate (MRR), Electrode Wear (EW), Surface roughness (SR), Surface Quality (SQ) and Dimensional Accuracy (DA). The materials used for the work were machined with different electrode materials such as copper, copper-tungsten and graphite. It was observed that the output parameters such as material removal rate, electrode wear and surface roughness of EDM increase with increase in pulsed current [5]. Investigations indicate that the output parameters of EDM increase with the increase in pulsed current and the best machining rates are achieved with copper and aluminium electrode [6]. Although, Electrical Discharge Drilling (EDD) using shaped tool electrodes improve response characteristics as proven by the previous studies, but time spent in electrode fabrication must also be considered as it aspects the overall productivity [7]. Considering the literature related to EDD using shaped tool electrodes, the proposed electrode had found to minimum electrode fabrication time i.e. 9 min for an electrode length of 3.2 mm [9]. The low wear resistance of electrodes like Cu, Cu alloys and graphite was a major problem for electrical discharge machining (EDM) operation [10]. Here an attempt has been made to develop a metal matrix composite (ZrB2–Cu) to get an optimum combination of wear resistance, electrical and thermal conductivity. The optimum thickness of silver coating over the copper tool electrode and optimum proportionate kerosene-servotherm dielectric were developed experimentally [10]. The copper tool electrode with silver coating of five microns reported slightly more material removal rate, very low tool wear rate, better dimensional accuracy and good surface finish than copper tool electrode with kerosene-servotherm (75:25) dielectric. The correct selection of manufacturing conditions and technique was one of the most important aspects to take into consideration in the majority of manufacturing processes and, particularly, in processes related to Electrical Discharge Machining (EDM). Optimization was one of the techniques used in manufacturing sectors to arrive for the best manufacturing conditions, which was an essential need for industries towards manufacturing of quality products at lower cost [11]. The work material was ED machined with copper, copper tungsten, brass and aluminum electrodes by varying the pulsed current at reverse polarity. Investigations indicate that the output parameters of EDM increase with the increase in pulsed current and the best machining rates are achieved with copper and aluminium electrodes [12]. However, the research results in this area are not many. And this will significantly affect the use of this technology in practice.

II. EXPERIMENTAL SETUP

The design of experiments is used to design the experiment in proper manner according to their number of parameters and levels. DoE minimizes repetition and improves accuracy of the experimentation. There are generally four methods used for design of experiments - Taguchi method, Response surface method, Mixture design method and Factorial method. Taguchi method has been used for designing experiment, according to which L16 orthogonal array has been selected. Experiments have been performed ac- cording to the set of combinations of factors as per L16 orthogonal array. Three input control variables are chosen such as peak current, gap-voltage and pulse-on time with four levels. For current, gap-voltage and pulse-on time values at various levels are 10, 20, 30 and 40 A; 40, 45, 50 and 55 V and 100, 500, 1000, and 1500 μs respectively. Ti-6Al-4V and Aluminum is used as workpiece and electrode, respectively. Once all the parameters and their levels have been selected, experiments are performed, and then results are interpreted analytically as well as graphically. For analysis the results graphs are generated by using MINITAB which shows the effects of all input control variables on output responses. Then ANOVA has been applied for evaluating the contribution of each input control variables in each output response. Tool wear rate (TWR) is considered as output responses. Then signal to noise ratio has been calculated for each response i.e. for TWR, lower the better approach are used. The experiments for Ti-6A-l4V titanium alloy machined by aluminum electrode are carried out according to design of experiments obtained by Taguchi Method. The experimental results obtained using aluminum electrode for TWR by varying current (I), pulse-on time (TON) and gap voltage (Vg) according to L16 orthogonal array are shown in **Error! Reference source not found.**.

Table 1. Experimental results

Expt. No.	**Current (I)**	**Gap Voltage (V_g)**	**Pulse-ON Time (T_{ON})**	**TWR mg/min**	**S/N**
1	10	40	100	0.0023	52.7654
2	10	45	500	0.0028	51.0568
3	10	50	1000	0.0041	47.7443
4	10	55	1500	0.0029	50.7520
5	20	45	100	0.005	46.0206
6	20	40	500	0.0058	44.7314
7	20	55	1000	0.0076	42.3837
8	20	50	1500	0.0087	41.2096
9	30	50	100	0.0068	43.3498
10	30	55	500	0.0098	40.1755
11	30	40	1000	0.0118	38.5624
12	30	45	1500	0.0124	38.1316
13	40	55	100	0.0106	39.4939
14	40	50	500	0.0145	36.7726
15	40	45	1000	0.0177	35.0405
16	10	40	1500	0.0212	33.4733

III. RESULTS AND DISCUSSION

3.1. ANALYSIS OF VARIANCE FOR TWR

From TWR ANOVA Table 2 the results found are, current and pulse-ON time with 100% and 98.8% confidence levels respectively they are the most notable parameters affecting TWR followed by gap voltage with confidence level of 80.8%.

Table 2. ANOVA of TWR using Aluminum Electrode

Source	DF	SS	MS	F-Value	P-Value	Contribution %
I	3	0.000364	0.000121	53.43	0	80
TON	3	0.000062	0.000021	9.13	0.012	13.62
Vg	3	0.000015	0.000005	2.17	0.192	3.29
Error	6	0.000014	0.000002			3.11
Total	15	0.000455				
S = 0.0015078 ; R-Sq = 97.00%; R-Sq(adj) = 92.51%						

The absolute values of tool wear show that there are two phenomena that regulate the wear characteristics of the tools: the erosion of the tool electrode material and the deposition of the workpiece material on the tool electrode. When high MRR conditions occur, large quantities of debris are produced and the quantity of material deposits increases on the tool electrode. In such conditions, the amount of actual material removed from the tool electrode also increases. Similarly, the amount of detritus stick on the tool electrode and the actual amount of the material separated from the workpiece for low MRR conditions is also less. Since tool wear rate was obtained by measuring the difference in weight of the tool prior and after machining, the collaborative effect of deposition and removal of material from the tool was considered in the calculated TWR. Main effects plot for TWR is shown in Figure .

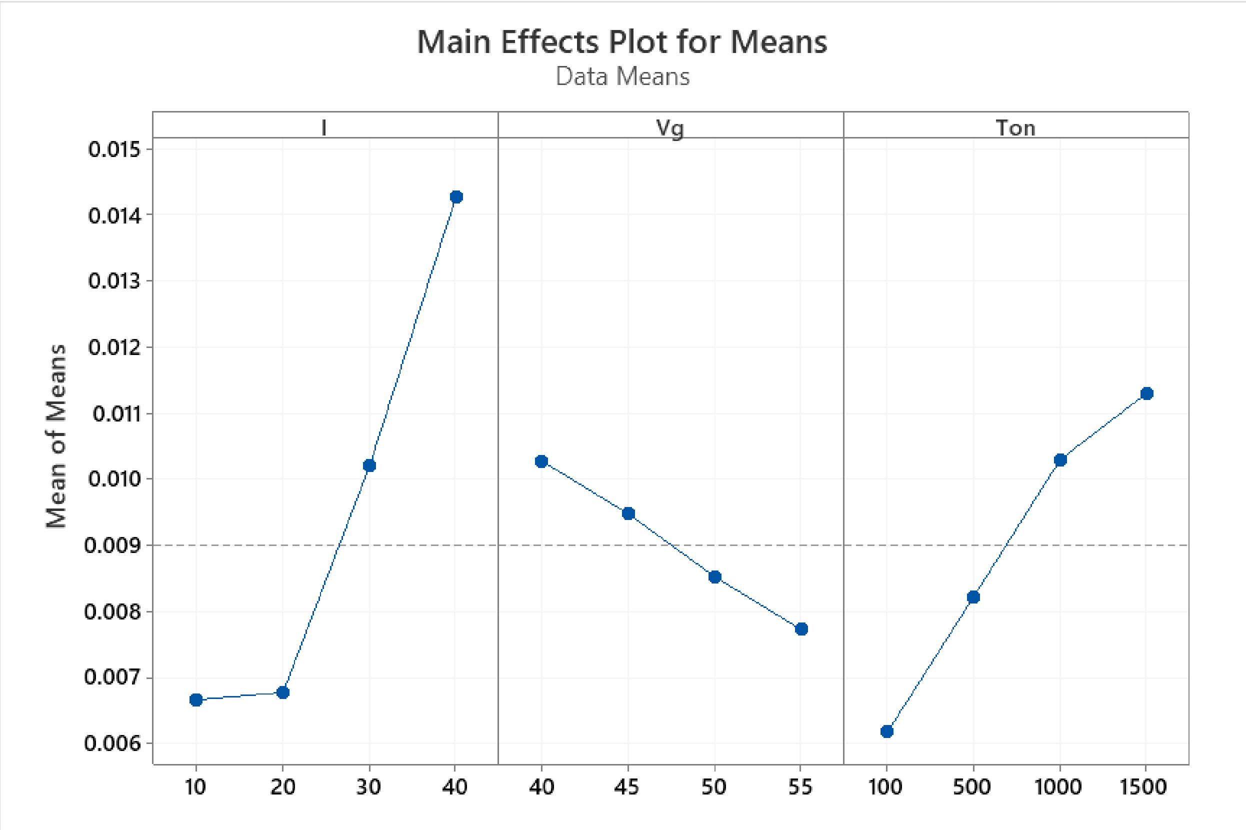

Figure 1 Main Effect Plot for TWR using Aluminum Electrode

Increase in current and pulse on time shows the increase in the tool wear rate (TWR) which can be determined from main effects graph, thereby increasing temperature leading to premature melting of the tool electrode. Therefore, as the current level is increased the tool wear rate is increased due to increment in the spark energy.

Optimization of TWR:

From the results of ANOVA of the mean and S/N ratio for TWR (Figure 2), the most significant main and interaction terms were obtained. These are tabulated in Table 3. TWR value is predicted at optimal conditions with the parameters that have the strongest influence.

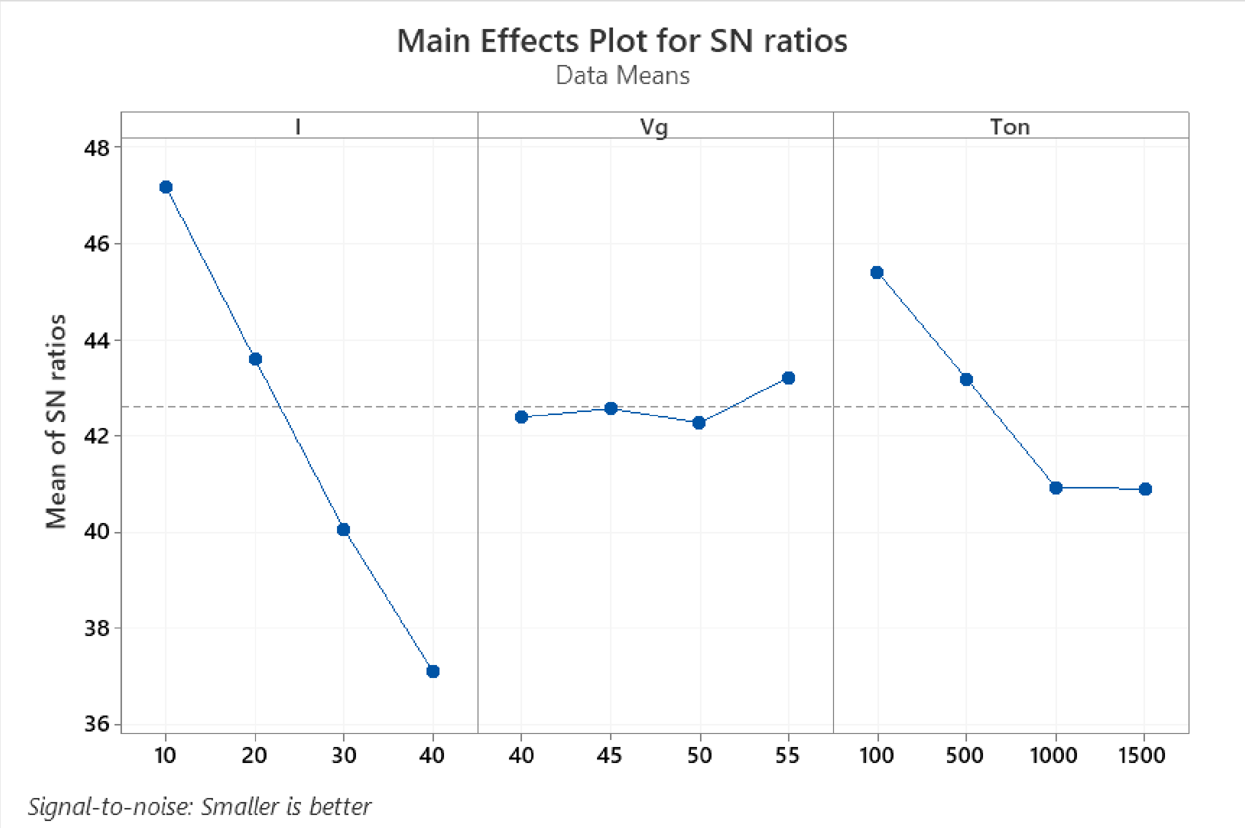

Figure 3.Main effects plot for S/N of TWR

Estimated value of TWR at optimal conditions:

Estimated value of TWR at optimal conditions, I1, Vg4, Ton1. TWR is determined by (1) [16] and TWR_{opt} = 0.0025 mg/min.

$$\overline{TWR}_{opt} = \overline{Vg_4} + \overline{I1} + \overline{Ton1} - 2.\overline{T} \quad (1)$$

IV. CONCLUSION

This research work was performed by EDM. Aluminum electrode was found that current (I) was the most notable parameter followed by pulse-on time (TON) and gap-voltage (Vg) respectively for the TWR as well as SR. This study aimed at optimising TWR using Taguchi methods to identify the most significant factors that influence TWR. The experiments were performed using Taguchi method of design of experiments and analysis were carried out using Minitab16 software. Ti-6Al-4V used as workpiece in both cases. The L16 orthogonal array performed with varying levels of Voltage, Current and Pulse on time to obtain Response Variables such as Tool Wear Rate (TWR) of EDM with Al electrode. The ANOVA was to identify the important parameters in prediction TWR. The optimal value of TWR was 0.0025 mg/min.

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