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Experimental Investigation of µEDM Process Parameters for Titanium Alloy with AlCrN Coated Electrode

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Abstract

Micro Electric discharge machining (Micro-EDM) is a non-traditional machining method, and it is widely used in mold, tool and biomedical manufacturing. Therefore, research to clarify this technology in practice is very necessary. In this article, the influence of technological parameters in micro-EDM with coated electrodes on quality indicators is investigated. The experiments were performed on titanium alloy strip (Ti-6Al-4V) and AlCrN coated tungsten carbide rod served as electrode rod. The technology parameters used in the study include Voltage (V), Capacitance (C) and Spindle Rotation (RPM), and tool wear rate (TWR), overcut (OVC) and depth (Z co-ordinate) are the Quality indicators in research results. Taguchi method is used to design experiments, and ANOVA is used to analyze the results of quality indicators. They conclude that C has greater effect on multi-performance characteristics than U and RPM. Z co-ordinate, OVC and TWR were increased with the increase in U, and C increases have resulted in Z co-ordinate and TWR both increasing. The influence of RPM on OVC and TWR is similar.

Keywords*:* µEDM, coated electrode, AlCrN, Taguchi, Ti-6Al-4V.

Introduction

Non-conventional processes, being of non-contact type and with a wide range of precision, are ideal for machining hardened materials. The progress in recent years in electronics industry, MEMS and rapid prototyping manufacturing could have been impossible without the development of non-conventional processes. Titanium alloy (Ti-6Al-4V) is used in various fields such as biomedical industry, aerospace industry, chemical process industry, etc. [1]. Due to machining limitations of conventional machining, non- conventional machining methods such as laser machining, electrochemical machining, and this alloy with an micro- EDM process used to machine some materials [2, 3]. The technique of using coated electrodes in micro-EDM is very new, and the technical and economic effectiveness of this technology has been proven in many studies [4]. However, the machining mechanism of micro-EDM is unclear, and different electrode materials will have a very significant influence on the machining efficiency. Therefore, using coated electrodes in micro-EDM is a very new field, so research to clarify this technology in practice is very necessary [5].

Many types of electrode materials (Al, Cu, Cu-W and brass,...) in micro-EDM have been experimentally studied, and their results have helped improve the application efficiency of micro-EDM [6]. The surface technology used creates an electrode surface material layer whose thickness can be in the range of 3-20 µm, so it can suit the working requirements of electrodes in micro-EDM. [7]. Research results in micro-EDM with coated electrodes were recently published, which showed the promise of this technology in this field. The surfaces of Cu, brass, molydenum and Cu-W electrodes in

EDM coated with Nickel and diamond – Nickel materials have been studied and evaluated [8]. The results show that the TWR of the diamon-nickel coating is the least. Znic coating on the brass surface has resulted in significantly improved MRR, TWR and SR in EDM [9]. Materials (Silver, Nickel, Zinc and epoxy) coated on the Cu electrode surface have helped reduce SR significantly [10]. SR with Znic coated electrode is the smallest, and the surface quality machined with EDM using epoxy coated electrode is the highest. Improving SR using EDM with coated electrodes is more effective than many other technical solutions [11]. TiN or TiAlN coatings lead to improved TWR and SR in micro-EDM compared to uncoated Cu electrodes, and TiN coating most significantly improves quality indicators [12]. The influence of parameters including V, I and Ton on EDM printing quality indicators has been investigated, and I is the most significant influencing parameter. The machining time in tool vibration in micro-EDM can be significantly reduced. Surface defects such as inhomogeneity, cracks, arc spots and black spots have been analyzed and reduced, while improving material removal rate with lower tool wear [13]. Using coated electrodes can significantly improve MRR, TWR, SR and EDM printing machining shape accuracy [14]. For each different type of coating material, the influence of the technological parameters adjusted in EDM/micro-EDM on quality indicators is different [15]. Therefore, clarifying this relationship in each specific study is very necessary. The Taguchi method is very suitable for research in EDM. The effect of tool rotation, pulse on time and workpiece vibration has been evaluated on MRR and SR in micro-EDM [16]. The I and Ton to investigate TWR and SR in micro-EDM for inconel 718 [17]. Curent (I) have a more significant influence on quality indicators than it does Ton. The influence of I and Ton on MRR and EWR in EDM using coated electrodes was investigated, and the results showed that they both have a significant influence on quality indicators [18]. The high aspect ratio can be machined with lower tool wear ratio with 50000rpm spindle speed in micro- EDM [19]. This is because rotation is effective in flushing debris particles from the gap and increasing cooling rate at the tool electrode surface [20]. Taguchi was used for experimental design and analysis [21-22].

The research results summarized above have shown that it is essential to determine the influence of technological parameters in EDM with coated electrodes on quality indicators. In this research, technological parameters including Voltage, Capacitance and Spindle Rotations in micro-EDM using AlCrN coated electrode are reviewed and evaluated. Taguchi Method is selected for DOE. Tool wear rate (TWR), overcut (OVC) and depth (Z co-ordinate) were selected as quality criteria for research.

Experimental setup

The design of experiment was performed using Taguchi method. In present work, Titanium alloy of Ti-6Al-4V used as workpiece material. Aluminum Chromium Nitride of 3.385 µm coated on Tungsten carbide. The mean diameter is 496.77 µm. In micro- EDM, dielectric fliud plays an important role during machining, and EDM oil were used as dielectric fluid. Hyper 10 Micro Electric Discharge Machining was used, Figure 1. The input technology parameters including Voltage, Capacitance and RPM, and their levels are described in Table 1. Recorded readings for L9 orthogonal array were mentioned below Table 2. The response variables chosen for study are Tool Wear Rate (TWR), Overcut (OVC) and Z co-ordinate (Z). Standard time of 15 minutes kept constant for all experiments. Results of Aluminum Chromium Nitride coated Electrode of nine experiments are shown in following Table 2, and the shape of the experimental workpieces is shown in figure 2.

Figure 1. Hyper 10 Micro EDM

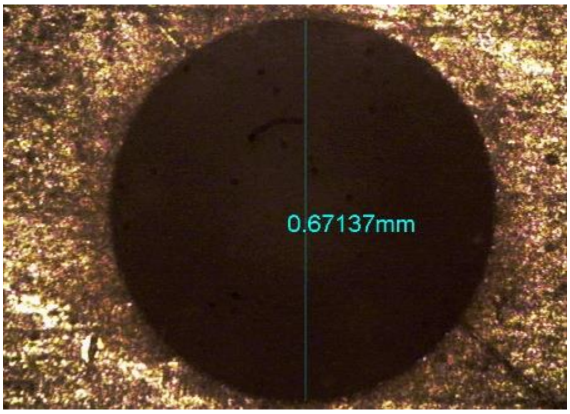

Figure 2. Photo of workpiece

Table 1. Input process parameters and their levels

Process Parameters	Levels		
	1	2	3
Voltage (V)	120	140	160
Capacitance (pF)	100	1000	10000
Spindle Rotation (RPM)	200	400	600

Table 2. Experimental results

Expt. No.	Process parameters			Response variables		
	Voltage (V)	Capacitance (pF)	RPM (rpm)	Z (mm)	TWR (mg/min)	Overcut (μm)
1	120	100	200	0.6678	0.00721	58.379
2	120	1000	400	1.4242	0.0425	27.718
3	120	10000	600	2.2088	0.071	53.715
4	140	100	400	0.9514	0.0231	82.456
5	140	1000	600	1.43	0.0472	32.974
6	140	10000	200	2.9222	0.0795	55.198
7	160	100	600	1.7223	0.0142	94.121
8	160	1000	200	1.4922	0.0411	60.933
9	160	10000	400	2.4727	0.0979	113.792

Results and discussion

a) ANOVA for Z Co-ordinate

The ANNOVA for Z Co-ordinate in micro-EDM using AlCrN coated Electrode shown in Table 3. ANNOVA for Tungsten Carbide Electrode was carried out by Minitab 17 Analysis Software. This result showed that C ($F = 7.93$) was the most significant process parameter for Z Co-ordinate, and U ($F = 1.05$) and RPM ($F = 0.15$) have negligible influence on Z Co-ordinate.

A method to achieve a specific depth in this case was non-compensated for wear of the electrode by constant electrode feeding in the Z-axis. This method requires an accurate model for estimating the volumetric wear ratio (the ratio of electrode wear and workpiece wear).

Certain factors affecting the wear ratio are difficult to assess and control, like flushing conditions in a deep hole for instance. This could easily result in wrong estimation of the wear ratio and therefore errors in the produced depth. The shape of the electrode also changes during machining towards a hemisphere, which causes errors in the produced bottom surface. One solution is to repeat the process a number of times with new or reground micro-electrodes until the required depth or pre-determined time period is obtained. This is called the multiple electrode strategy.

The main effect plots for depth of Aluminum Chromium Nitride coated electrodes shown in Figure 3. U and C have similar effects on the Z Co-ordinate, and an increase in U and C has resulted in an increase in the Z Co-ordinate. Depth increases linearly with Capacitance. The reason may be that their increase leads to an increase in the energy of the sparks, and this leads to an increase in the amount of workpiece material that is melted and evaporated. At lower Voltage gap i.e. 120V and lower Capacitance level i.e. Level 1 (100pF) depth is less due to less energy produced in electrode gap. This is due to combine effect of non-compensated TWR from bottom of the electrode as well as at higher voltage due to carbon layer formation reduction in spark energy takes place. Hence depth increases linearly up to 160V voltage and 10000 pF.

In the case of RPM, it provides better flushing action due to revolutions of the tool. As revolutions of tool increase flushing actions stimulates the ionization and plasma channel formation. Hence RPM is directly related to flushing action in spark gap. But researchers in MEDM always cope with randomness of flushing action of dielectric fluid. This randomness in flushing action of dielectric fluid produces anomalies at 200 rpm and 400rpm, reduces depth. Beyond 600rpm it shows satisfactorily increase in depth.

Table 3. Analysis of Variance for Z Co-ordinate

Source	**DF**	**SS**	**MS**	**F ratio**	**P value**	**Contribution (%)**
Voltage	2	0.46295	0.23147	1.05	0.487	10.39
Capacitance	2	3.48415	1.74207	7.93	0.112	78.25
RPM	2	0.06566	0.03283	0.15	0.870	1.47
Error	2	0.43936	0.21968			9.86
Total	8	4.45211				
S = 0.468701 R-Sq = 90.13% R-Sq(adj) = 60.53%						

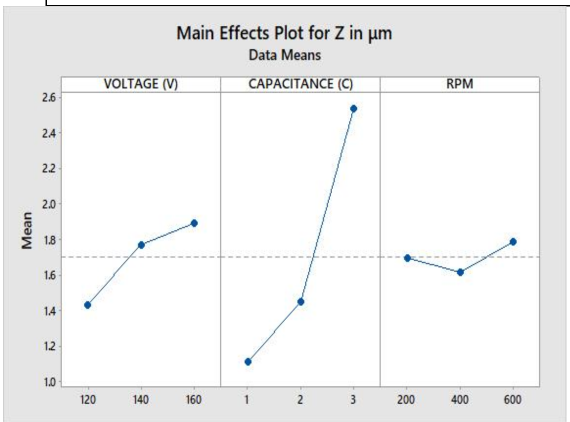

Figure 3. Main Effects Plot for Z Co-ordinate

b) Analysis of Variance for Overcut

From Table 4, it was cleared that U (F = 21.76) and C (F = 18.46) play dominant role in Overcut but remaining parameter RPM (F = 3.46) was non-significant for OVC of micro-EDM with AlCrN coated micro electrode.

Figure 4 shows the influence of technological parameters on quality indicators. When U = 120 – 160 V, OVC increased significantly. This is because the increase in C led to an increase in material removal productivity. The influence of C on OVC in micro-EDM with coated electrodes is opposite to the influence of RPM.

OVC is largest at C = 100 pF and RPM = 400 rpm, and it is smallest at C = 1000 pF and RPM = 200 rpm. The reason for this is since the low capacitance causes short circuit, resulting in no material removal; When the RPM is small, removing particles from the machining area is difficult, and this leads to increased occurrence of short circuits.

Table 4 Analysis of Variance for Overcut

Source	DF	SS	MS	F ratio	P value	Contribution (%)
Voltage	2	3027.4	1513.68	21.67	0.044	48.60
Capacitance	2	2579.0	1289.51	18.46	0.051	41.40
RPM	2	483.1	241.55	3.46	0.224	7.75
Error	2	139.7	69.85	-	-	2.24
Total	8	6229.2	-			
S = 8.35760 R-Sq = 97.76% R-Sq(adj) = 91.03%						

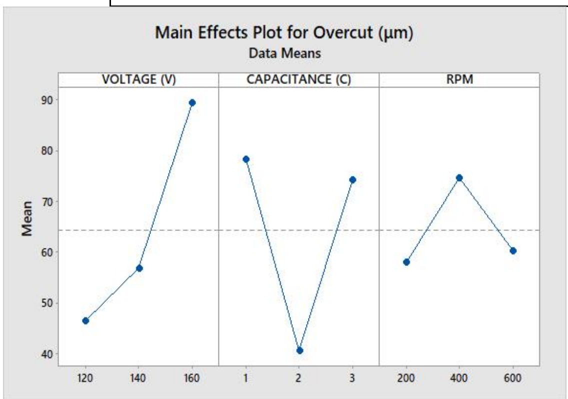

Figure 4. Main Effects Plot for Overcut

c) Analysis of Variance for TWR

From Table 5 it was cleared that Capacitance plays dominant role in TWR of electrode but remaining parameters such as Voltage and RPM were non-significant for TWR of AlCrN coated electrode. The absolute values of tool wear shows that there are two phenomenon governing tool wear characteristics: erosion of electrode material and deposition of material on the electrode. When high spark energy conditions exist, large amount of debris is formed and the amount of material deposited on the tool increases. Under such conditions, the amount of actual material removed from the tool also increases.

Similarly, for low saprk conditions the amount of debris deposited on tool and amount of actual tool material removed is also low. Since TWR was calculated by measuring the difference in tool weight before and after machining, the combined effect of deposition and removal of material from tool was included in the measured TWR. The constant value of TWR indicates that the difference between material removed from tool and material deposited on tool remains constant even when the process parameters are changed. Main effects plot for TWR is shown in Figure 5.

In this experiment three levels of voltage were used i.e. 120V, 140V and 160V. Table 3, it was observed that erosion of tool was maximum at 10nF and deposition of workpiece material on tool at 140V and 160V. During assessment of TWR it is found that for 140V and 160V, initially TWR was higher but once protective layer of AlCrN deposition covers the surfaces then TWR as well as Z Co-ordinate reduces with respect to time. From main effects plot it can be said that tool wear increases as increase in Voltage and Capacitance. This was due to at higher product of Voltage and Capacitance produces stronger spark thereby temperature increases so melting starts at earlier, also spark energy is low at low lower levels. Hence, as the Capacitance increases the tool wear rate is increases due to increasing spark energy. From main effect plot it's clear that, as RPM increases TWR also increase. This is due to, RPM stimulates good flushing action, therefore MRR and TWR also slightly increases at higher RPM.

Table 5 Analysis of Variance for TWR

Source	DF	SS	MS	F ratio	P value	Contribution (%)
Voltage	2	0.000213	0.000106	3.46	0.224	2.83
Capacitance	2	0.006983	0.003491	113.59	0.009	93.00
RPM	2	0.000251	0.000126	4.09	0.197	3.34
Error	2	0.000061	0.000031			0.81
Total	8	0.007508				
S = 0.0055442 R-Sq = 99.18% R-Sq(adj) = 96.72%						

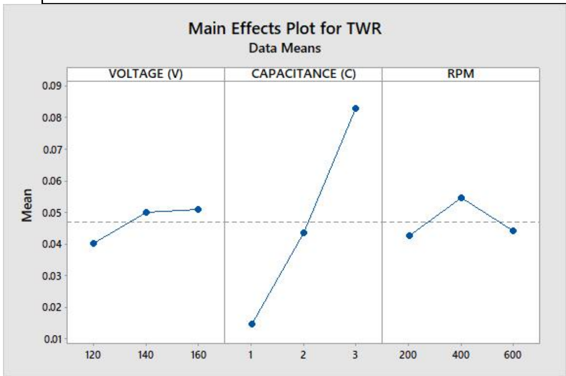

Figure 5. Main Effects Plot for TWR

Conclusion

The effect of parameters i.e. Voltage, Capacitance and RPM were evaluated using ANOVA and factorial design analysis. The purpose of the ANOVA was to identify the important parameters in prediction of Tool Wear Rate (TWR), Overcut and Z Co-ordinate (Depth) in Micro EDM process using AlCrN coated electrode. The experiments were performed using Taguchi method of design of experiments and analysis were carried out using Minitab17 software. Some results consolidated from ANOVA and plots are given below: TWR is significantly increased with the increase of V, C. And the influence of C is the largest, and it is the smallest with V; OVC is changed significantly with the change of technological parameters. The influence of C and RPM on OVC is quite similar, and their effect on OVC is opposite to that of RPM; C has a significant effect on Z, and the degree of influence V and RPM on Z is negligible.

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