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Effect of discharge energy during micro-electro discharge milling on dimensional accuracy and surface quality of fabricated micro-features

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Abstract

Micro-electro discharge milling (µ-ED milling) process has emerged as a promising solution for fabrication of complex 3D micro-features in any conductive material, especially, in difficult-to-cut materials. However, the higher amount of discharge energy degenerates the accuracy of fabricated micro-features. It is crucial to investigate effect of discharge energy on the dimensional accuracy of fabricated micro-features. Therefore, in this paper, the dimensional accuracy of fabricated micro-features fabricated by µ-ED milling process has been investigated. The results indicate that discharge energy have considerable effects on dimensional accuracy of fabricated micro-features.

Keywords: micro-electro discharge, milling, discharge energy, micro-features, dimensional accuracy.

1. INTRODUCTION

The increasing demand for precise micro-features in the field of medicine, electronics and aeronautics and biomedical is becoming a new challenge in the field of micro machining. This has led to the development of various micro machining processes [1]. The un-conventional machining processes have gained major attraction owing to their many significant advantages over conventional machining processes.

Micro-electrical discharge machining (µ-EDM) is a thermal process for contactless material removal of electrically conductive materials, including materials that are difficult to machine with conventional manufacturing technologies such as carbides, superalloys, tool steels or electrically [2]. The removal the material in µ-EDM is due to a series of repetitive electric sparks that occurs between the tool and the work piece submerged in dielectric medium which leads to guarded erosion of the material. High frequency sparks occurring continuously and effectively removes the work piece material by melting and evaporation. In µ-EDM, the combination of low discharge energy is utilized for controlled removal of micron sized particles of the workpiece.

In micro-EDM milling (µ-ED milling), a rotating cylindrical or tubular rod is used as tool electrode and the kinematics is the same as in conventional CNC milling. The applications µ-ED milling are extended to various market sectors such as automotive, aerospace, medical, and textile. The shape and size of the geometry being machined dictates the tool path (electrode movement) strategy, attributes to the dimensional accuracy, surface integrity, machining time, consistency in spark gap and mode of material removal for which no systematic study has been performed yet and the process phenomenon of µ-ED milling is still an unsolved research problem.

In most of the µ-ED milling literature, researchers have discussed various aspects including material removal rate (MRR) [3, 4], tool wear [4, 5], influence of machining parameters [6], machining of different work and electrode materials, use of different electrodes [7], and discharge plasma characterization [8], but very limited studies dealt with discharge energy effect on dimensional accuracy of features.

The present paper addresses the effect discharge energy of µ-ED milling on dimensional accuracy of fabricated micro-features. The common shapes like triangular and straight micro-channels have been fabricated at different discharge energy and then effect of discharge energy of dimensional accuracy of fabricated feature has been investigated.

2. EXPERIMENTAL SETUP

Micro machining center MIKROTOOLS: DT-110 was used to perform the experiment. A three axis computer numerical control based control was used to achieve the complex tool path trajectories. The machine has a linear scale resolution of 0.1 micrometer. Cylindrical electrode of Tungsten Carbide with a diameter of 300 µm was used in the experiments. Inconel 718 superalloy was used as the workpiece with dimension of 30mm×10mm×3mm. Tool has been dressed before each operation to avoid any initial errors. The tool was mounted on the spindle which rotates at a speed of 2000 RPM and moves along Z-Axis to impart depth in the machined geometry whereas the workpiece moves along X-Y Plane with a feed rate of 0.240mm per min. In this experimentation, a tool path wherein the tool electrode follows the shape of the pocket (cavities to be machined) using parallel paths, separated by a constant step over of 50% is adopted. Both features were machined to a depth of 0.5mm in multiple pass method. A continuous stream of the dielectric was fed between the electrode and work piece. A voltage of 130V was applied through an RC circuit build in the machine. The trajectory and depth of the geometries was controlled by the CNC program and multiple number of passes were produced to obtain the desired depth. Two basic shapes were formed during the experiments at different discharge energy values. The machining parameters are shown in Table 1. The dimension of shapes is given in the Table 2.

Table 1. Machining Parameters Used

Parameters	Values
Discharge energy	50 µJ, 500 µJ, 1200 µJ
Dielectric	Total®
Polarity	Work Positive
Workpiece	Inconel 718
Tool electrode	Tungsten Ø300 µm
Spindle Speed	2000 RPM
Feed Rate	0.240 mm per min

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Initially, the performance of µ-EDM milling has examined in-terms of MRR, tool wear (TW), and then then accuracy of fabricated micro-features have been discussed.

Table 2. Geometries and their dimensions

Geometry	Dimension
Triangle	Height = 860 µm
Straight channel	Width = 300 µm

3. RESULTS & DISCUSSION

3.1 EFFECT OF DISCHARGE ENERGY ON DIMENSIONAL ACCURACY

The effect of discharge energy on MRR and TW is shown in Fig. 1. It has been observed that both the MRR and TW values are greatly influenced by the discharge energy in µ-ED milling. Higher the discharge energy, more will be material removal by melting and evaporating the workpiece. The similar behavior of increase of TW with an increase in discharge energy has been observed. The higher discharge energy will cause high tool wear too. Therefore, it can be commented that the different discharge energy will also have significant effect of dimensional accuracy of fabricated micro-features.

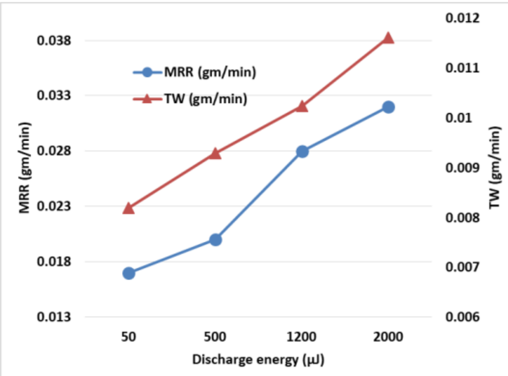


Fig. 1 Effect of discharge energy on MRR and TW

As discussed in section 2, the different micro-features have been fabricated at different discharge energy. Each experiment is repeated three times to check mean and standard deviation in runs.

The dimensional inaccuracy and size of feature increases with an increase in discharge energy for triangular cavity, Fig. 2. The height of triangle is larger than the required one for all discharge energy levels and particularly seen largest for discharge energy of 1200µJ. The mean error along with standard deviation for different discharge energy for triangular cavity is shown in Table 3.

Table. 3 Effect of discharge energy on accuracy of triangle

Discharge energy (µJ)	Measured Dimensions (µm)			Mean Error	S.D.
	1	2	3		
50	922	918	912	57.33	6.03
500	958	971	977	108.67	12.40
1200	1018	1034	1068	183.34	30.76

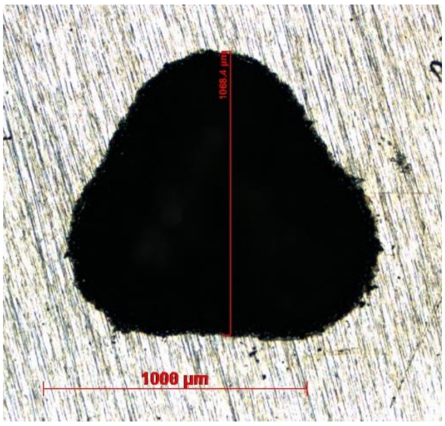


Fig.2 Microscopic image of triangle

In this case, the non-uniform discharges occurs due to deflection of the electrode which alters the spark gap for the instant continuously. Further corner effect error was also observed in the discharge as unlike in the shaped electrode, the cylindrical tungsten electrode is unable to produce sharp corners.

In case of straight channel also the increase of width of micro-channels was observed as that of hole and triangle. There is continuous variation in width of particular channel is also observed. Therefore, six measurements along length of micro-channels were performed and mean of these values considered for further analysis (Fig.3). Table 4 presents the effect of discharge energy on dimensional accuracy of fabricated channels.

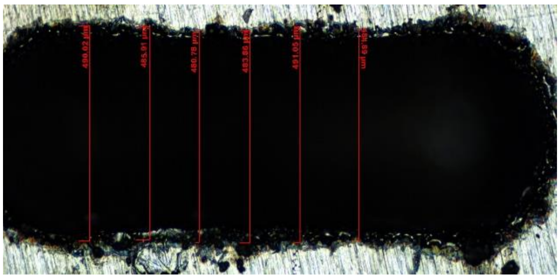


Fig.3 Microscopic image of straight channel

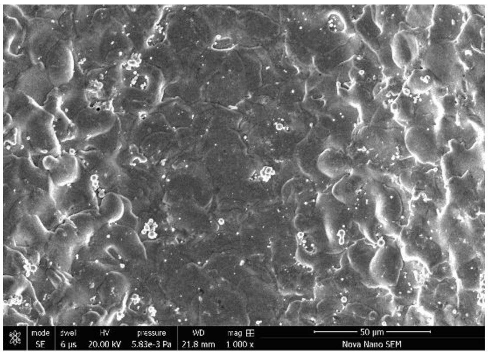
Table. 4 Effect of discharge energy on accuracy of channel

Discharge energy (µJ)	Measured Dimensions (µm)			Mean Error	S.D.
	1	2	3		
50	325	332	328	28.33	4.96
500	347	357	361	55.00	9.27
1200	387	372	391	83.33	13.08

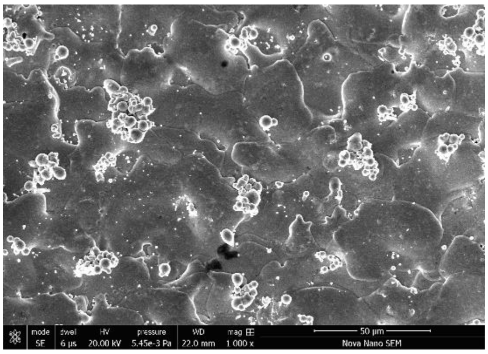
Overall, for considered micro-features, the dimensional accuracy depreciate with an increase in discharge energy. In an EDM process, the tool and the workpiece are immersed in a dielectric medium with a small gap (5–10 mm) in between. The dielectric medium will be broken down when a proper voltage between the two electrodes is applied. In the process of discharge breakdown, electrons are emitted from the cathode to the anode, which ionizes the dielectric medium and forms a plasma channel between the two electrodes. The size of plasma channel formed is directly proportional to the discharge energy per spark [9]. For RC circuit, the discharge energy is proportional to half of capacitance and voltage[2]. Therefore, higher discharge energy, larger width of plasma channel attribute of melting and evaporation of larger workpiece area. Thus, creating larger crater size and removing more material per spark. This whole action results in decreased accuracy of fabricated micro-features.

3.2 EFFECT OF DISCHARGE ENERGY ON SURFACE QUALITY

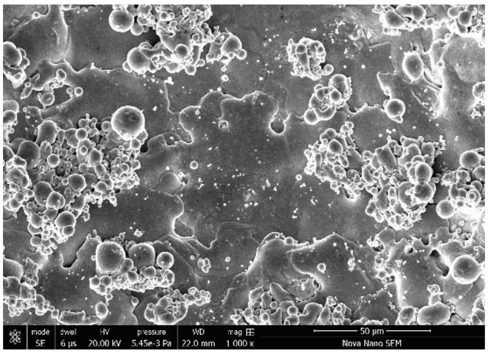
The surface quality of fabricate features was investigated, only for straight channel, using the images captured using SEM (Nova NanoSEM 450). Fig. 4 shows the images of micro-channels fabricated at different discharge energy.



(a) At 50 µJ



(b) At 500 µJ



c) At 1200 µJ

Fig.4 Surface quality at different discharge energy

It was recognized that the discharge energy has a considerable effect on surface quality of channel produced. The discharge energy removes the material from the workpiece by melting and evaporation of material leaving behind the craters. The dielectric fluid causes the rapid cooling and quenching of molten metal and thus leading to the formation of globules which are non-crystalline sphere-shaped specks [10]. The discharge energy is acting onto the workpiece notably affects the shape and size of the globule formed. At lower discharge energy, the globules size appear to be tiny as compared to the globules at high discharge energy. Moreover, the size of the globules were not same at particular energy level owing to superimposing of craters and rotation of electrode.

4. CONCLUSIONS

Micro-electric discharge milling is a competent process for fabrication of three-dimensional miniaturized features specifically in difficult-to-cut materials. However, understanding the effect of discharge energy on feature’s dimensional accuracy and surface quality is important and has not been reported still. Therefore, in this paper, we investigated the effect of discharge energy on dimensional accuracy and surface quality of common micro-features including triangle and straight micro-channel. It is observed that with an increase in discharge energy, the error in fabricated micro-channel increases. Also, surface quality deteriorate with increase in discharge energy.

For a better accuracy and surface quality of micro-features, the low discharge energy is appropriate. This study will serve very important guideline in fabrication of miniature devices from industrial perspective.

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