DTU Library

Investigations into methods for improving productivity and quality in dry EDM process

Puthumana, Govindan; Joshi, S. S.

Published in:
Proceedings of the International Conference on Precision, Meso, Micro, and Nano Engineering

Publication date:
2013

Document Version
Peer reviewed version

Eighth International Conference on Precision, Meso, Micro and Nano Engineering, NIT Calicut, India, 13-15 December, 2013.

Investigations into methods for improving productivity and quality in dry EDM process

Govindan, P.,[1] Joshi, S. S.[2]

[1]Ph.D. candidate, Department of Mechanical Engineering
Indian Institute of Technology Bombay, Mumbai-400076, India.
Email: govindanp2002@gmail.com
[2]Professor, Department of Mechanical Engineering
Indian Institute of Technology Bombay, Mumbai-400076, India.
Email: ssjoshi@iitb.ac.in

Abstract: One of the other reasons for low productivity (MRR) in dry EDM is ineffective debris removal from the inter-electrode gap. It is anticipated that use of slotted tool electrodes would be beneficial for the effective debris disposal. On the other hand, from surface quality point of view, the use of helium gas dielectric having the high heat capacity would be helpful. In the dry EDM using helium, the speed of rotation (N) is the major contributor to an increase in MRR than the current (I). Observation of topography of dry EDMed surfaces shows that the use of helium gas dielectric causes development of lesser number of micro-cracks than that of with the use of oxygen as dielectric.

Keywords*: Dry EDM, MRR, slotted electrode, surface quality, helium gas dielectric, surface topography.*

1. INTRODUCTION

Dry EDM is a prospective alternative to the liquid dielectric EDM process. It encompasses flow of gaseous dielectric through a tubular tool electrode to the inter-electrode gap [1]. The key features of dry EDM are as follows: i) facilitates machining in various orientations including vertical, ii) high-pressure gas flow through a tubular tool electrode helps flush out the molten metal, iii) dielectric liquid, complex dielectric circulation and filtration arrangements are not necessary, and iv) process is characterized by low to almost zero tool electrode wear [2-5]. However, there are a few challenges in dry EDM operation; the main among them are: i) inefficient debris evacuation and ii) poor quality of machined surfaces. One of the techniques to resolve this issue is the use of mist EDM [2]. It uses a mixture of gas and atomized water vapour, as a dielectric. The mist EDM causes a decrease in efficiency, high tool wear, pollution, difficulty in cleaning and piping required for mist flow. Another developing technology, viz. powder mixed EDM [5], environment-unfriendly and causes an increase in the cost of machining.

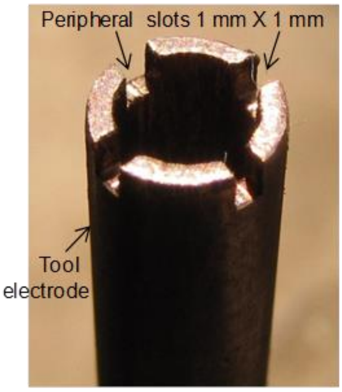
Therefore, this paper proposes a dry EDM process with the alternatives to improve dry EDM performance, involving the use of slotted electrodes as well as the helium gas dielectric. In the method using slotted tool, the methodology used here is to change the geometry (face shape) of the tool electrode, by providing marginal slots on it. It is envisaged that the method helps better escape of gases and debris removal, thereby improving the process MRR. On the other hand, the experiments using helium gas dielectric are aimed at improving machined surface quality in the dry EDM process. It is expected that the helium gas dielectric would facilitate appropriate cooling of the machined surfaces. It is known that the helium gas has the highest heat capacity among the dielectrics.

2. EXPERIMENTAL WORK

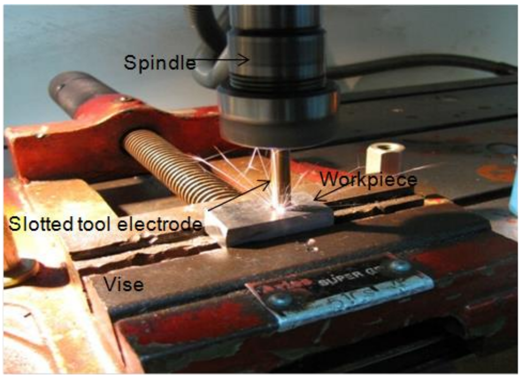
The objectives of this experimentation are to: i) improve the MRR of the dry EDM process by using slotted (square shaped) tool electrode, and ii) improve the quality of dry EDMed surfaces using helium gas dielectric. Analysis of MRR, TWR and topography of machined surfaces has been included in this work.

2.1 Specifications of machine, dielectric, work and tool

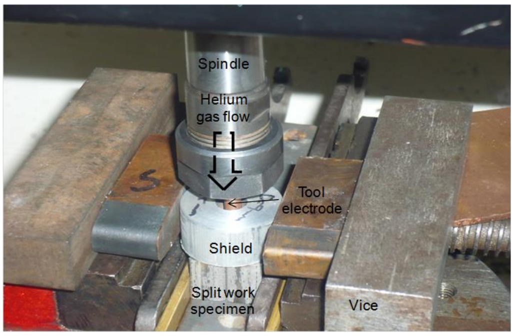
All the dry electrical discharge drilling experiments were performed on a CNC EDM machine with a MOFSET pulse generator. Fig 1 *a-c* shows the details of the dry EDM experimental set-up.



a.



b.



c.

Fig. 1 *a-c* Photographs of dry EDM experimental set-up *a*. slotted tool electrode, *b*. sparking in dry EDM using slotted tool, and *c*. using helium gas dielectric

The gaseous dielectric is supplied through the central hole on the copper pipe electrodes. The electrodes were finish turned and were grounded at the ends. Further, the geometry of some of the electrodes was modified by making equally spaced square cut-outs along the periphery of the pipe electrodes. Stanless steel 304 (SS 304) in the form of split specimen [6] was used as the workpiece for all the experiments. The details of the experimentation and specifications of tool, workpiece and dielectric are shown in Table 1.

2.2 Experimental design

In this study, six process parameters were chosen and experiments were planned using Taguchi's design [7], Table 1. Two sets of experiments were conducted on dry EDM under varying conditions of input parameters, see Table 2.

- L_{16} experiments using slotted tubular copper electrode
- L_8 experiments using tubular copper electrodes with the application of helium gas dielectric, see Fig.1 *a-c*.

Table 1 Details of the dry EDM experimentation

Experiment	Aim of the experiment	Design	Tool/ Workpiece/ Dielectric
Using slotted tool electrode	To improve MRR in dry EDM.	L_{16} orthogonal array	Cu/SS 304/ O_2
Using helium gas dielectric	To improve quality of dry EDMed surfaces.	L_8 orthogonal array	Cu/SS 304/ He

It is known that gap voltage (*V*), discharge current (*I*) and pulse off-time (T_{off}) are the main factors governing the supply of energy to the spark in a dry EDM process, and their variation is directly proportional to MRR of the process [1]. It is expected that non-electrical factors, viz., electrode speed (*N*), gas pressure (*P*) and the clearance between shield and the tool electrode (*C*) influence the stability of the process (see Table 2).

The use of tool electrodes with peripheral slots is a method aimed to improve debris evacuation so as to improve the MRR in the dry EDM. The other favourable effects include: i) better circulation of gaseous dielectric and ii) cooling of tool surfaces to prevent damage because of heating. Further, it is anticipated that the slots on periphery of the tool electrode, would help material removal in dry EDM in the following way:

- The slots would help blow away the discharge plasma and replenish the dielectric strength in the inter-electrode gap at a faster rate, which help the stability of sparks in dry EDM [2].

- The slots would facilitate effective circulation of dielectric, thereby quicker and easier debris evacuation from the sparking region could take place at the end of a discharge.
- The slots would help in cooling of the wall region of the pipe electrode surrounding the spark, which could minimize debris deposition [3,4] due to a large flow of oxygen dielectric.

The set of experimentation using helium gas dielectric is aimed at improving machined surface quality in dry EDM process. This enhancement would be because of the following:

- The heat capacity of helium gas (5.19 J/g K) is six times higher than oxygen (0.92 J/g K), which would help prevent heat concentration on the machined surfaces. As a result, the dry EDMed surface is expected to be smoother and with lesser resolidification of molten work material [2].
- For the same input electrical energy, the plasma generation is lower in helium than in oxygen [4], which would reduce extra heating of the work surface during each spark, so as to lower surface damages such as formation of micro-cracks and black patches.
- The helium gas has a refractive index eight times lesser than oxygen [2], which would help lower lateral deflection and spread of electrical sparks in the atmospheric air. Thus, improvement of surface quality of dry EDMed features is anticipated.

2.3 Response variables

In addition to MRR, TWR and depth achieved, an attempt has been made to analyse the surfaces generated. The MRR and TWR were determined by using precision weighing scale. The depth of the hole achieved was measured using Nikon Tool Maker's Microscope. The topography of machined surface was observed using the scanning electron microscope.

3. RESULTS AND DISCUSSION

The results of the experiments are presented in the following sections.

3.1 Comparative analysis of MRR

In order to understand the effect of input parameters on the MRR, statistical analysis using ANOVA has been performed on the data of MRR obtained from each experiment. The results of this analysis are summarized in Table 3. The AOM plots indicating variations of MRR with the input parameters are presented in Fig. 2, 3 and 4. It is observed from these figures that the MRR using slotted electrodes is 20-60 times higher than using the helium gas.

Table 2 Details of the dry EDM experimental design

Experim-ent	Input parameters, Levels and the response variables					
Using slotted tool electrode	Input parameters	Levels				Response variables
	Voltage (V), V	50	60	70	80	MRR, TWR, Depth
	Current (I), A	9	12	15	18	
	Pulse off-time (T_{off}), μs	0	18.1	40.0	66.6	
	Pressure (P), MPa	0.1	0.15	0.20	0.25	
	Spindle speed (N), rpm	100	200	300	400	
Using helium gas dielectric	Input parameters	Levels		Response variables		
	Voltage, V (V)	50	80	MRR, TWR, Depth and Surface topography		
	Current, I (A)	12	18			
	Pulse off-time, T_{off} (μs)	22	67			
	Helium pressure, P (MPa)	0.15	0.25			
	Spindle speed, N (rpm)	100	300			
	Shield clearance, C (mm)	4.0	5.0			

Table 3 Statistical significance of input parameters on MRR for experiments using different process improvement methods

Experiment using	Input parameters and their statistical significance on MRR					
	V (V)	I (A)	T_{off} (μs)	P (MPa)	N (rpm)	C (mm)
Slotted electrode	√	√	√	X	√	**not used**
Helium gas dielectric	X	√	X	X	√	X
√ - statistically significant, X – not statistically significant						

It is observed from ANOVA results presented in Table 3 that the voltage (V) is significant in influencing MRR only for experiments using slotted electrodes. Further, the AOM plots presented in Fig. 2 shows that MRR decreases with voltage. It is expected that an increase in voltage increases discharge energy and consequently the MRR.

The discharge current (I) significantly influences MRR in all the experiments performed (Table 3). Further, the AOM plots presented in Fig. 3 show that the MRR increases linearly with current in all the cases.

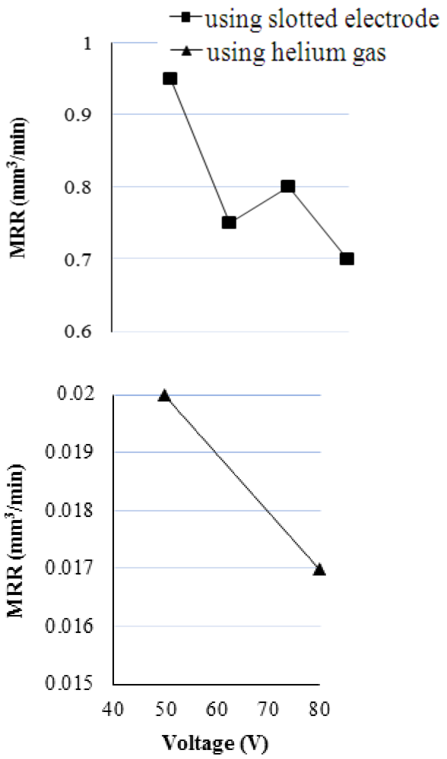


Fig. 2 A comparison of AOM plot for MRR in experiment with slotted electrode and using helium gas dielectric, with voltage (V)

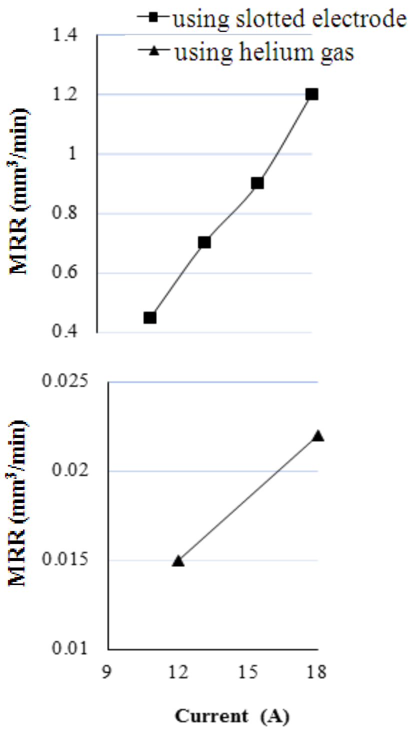


Fig. 3 A comparison of AOM plot for MRR in experiment with slotted electrode and using helium gas dielectric, with current (A)

It is known that with an increase in current, flow of electrons increases from cathode to anode. As a result, discharge energy increases, resulting in a higher MRR [4, 5]. Similar results are obtained in all the experiments performed. The pulse 'off-time' is significant in influencing MRR, only in the experiment using slotted electrodes. From the AOM plots (Fig. 4), it is observed that beyond a pulse 'off-time' of 40 µs, the MRR decreases linearly. Hence, the highest MRR is observed close to the 'quasi-explosion' point at which pulse 'off-time' is one-sixth of pulse 'on-time' [5]. This strongly supports the earlier investigations on dry EDM under 'quasi-explosion' mode [1, 2]. The pressure of gaseous dielectric (*P*) is not significant in influencing MRR in any of the experiments (Table 3). An increase in pressure does not cause much variation to the MRR. The spindle speed (*N*) is statistically significant in influencing MRR for all the experiments. Further, there is an increase in MRR with speed in most of the cases (the plot is not presented here). The electrode rotation provides a blowing action to the molten debris particles [2].

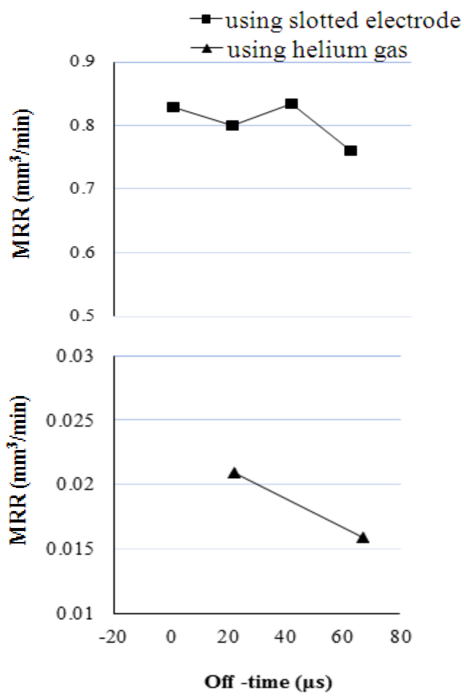


Fig. 4 A comparison of AOM plot for MRR in experiment with slotted electrode and using helium gas dielectric, with pulse off-time (µs)

3.2 Comparative analysis of TWR

The effect of each method used in these experiments on TWR is discussed below. In all these categories of experiments, deposition on the tool electrode is found to reduce significantly. This implies that all the measures used are found to be effective in reducing the metal deposition on the tool electrode surface. In the experiments using slotted electrodes, the values of TWR are close to zero or positive (0.002 to 0.006 mm^3/min). This specifies that with peripheral slots, the debris deposition on tool electrode is completely eliminated. However, the slots on electrode periphery reduce the effective cross-sectional area supporting the thermal load, sometimes causes minor wear on the electrode. Thus, the slotted electrodes help in

- reducing the attachment of a fraction of molten workpiece material to the tool electrode, which normally occurs in dry EDM.
- increasing the access of oxygen gas to entire region of tool electrode close to the discharge locations, so as to protect the electrode from wear by forming an oxide layer around the tool electrode [1].
- cooling the walls of the slots on the tool electrode, so as to reduce thermal damage and chances of arcing, unlike in the case of dry EDM [4,5].

In the experiments using helium gas dielectric, no deposition of material on the tool electrode was observed. Nevertheless, a minor wear was observed at the tool electrode surfaces.

3.3 Comparative analysis of depth achieved

Analysis of the depth achieved was performed in two experiments, one using slotted electrodes, and, second, using helium gas dielectric. The statistical significance of input parameters on depth achieved in both in the case of slotted electrode experiment and the experiment using helium gas dielectric is shown in Table 4. This is because of a related increase in depth with an increase in MRR.

The voltage (*V*) is significant in influencing depth achieved only in the case of experiment using slotted electrodes. An increase in voltage (*V*) leads to a decrease in depth achieved (see AOM plots in Fig. 5). This could be because of an increase in inter-electrode gap and a consequent plasma growth, as discussed earlier in analysis of MRR. Since an increase in MRR is proportional to the depth achieved, the effects are identical.

Table 4 Statistical significance of input parameters on depth achieved for experiments using different process improvement methods

Experiment using	Input parameters and their statistical significance on depth achieved					
	V (V)	*I* (A)	T_{off} (µs)	*P* (MPa)	*N* (rpm)	C (mm)
Slotted electrodes	√	√	X	X	X	-------
helium gas dielectric	X	X	√	√	√	√

√ - statistically significant, X – not statistically significant,

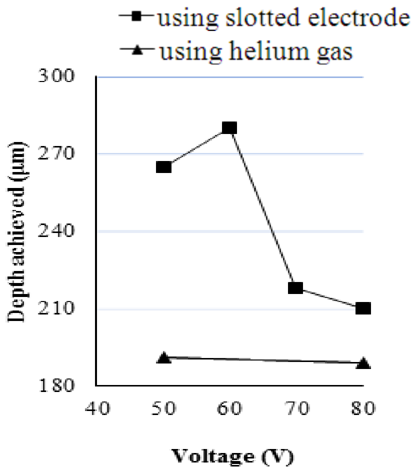
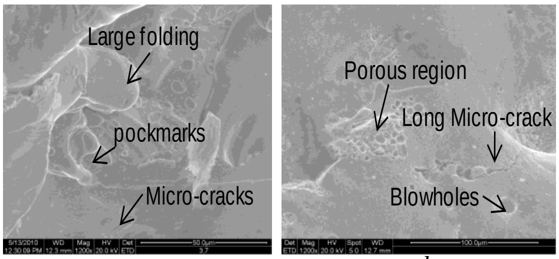


Fig. 5 A comparison of AOM plots for depth achieved using slotted electrodes and helium gas dielectric with voltage

With an increase in current (*I*) from 9 to 18 A, the depth achieved also increases linearly (the plot is not presented here) in the experiment using slotted electrodes. A similar trend is observed in the experiment using helium gas. Again this effect is due to an increase in discharge energy, with an increase in current (the plots are not presented here). The pulse 'off-time' is significant only in experiment using helium. With an increase in pulse 'off-time' (T_{off}), depth of the hole achieved decreases (the plots are not presented here). All the dry EDM experiments were done at a constant pulse 'on-time' (T_{on}) of 200 µs. With an increase in pulse 'off-time' (T_{off}), spark energy decreases, resulting in a lower depth.

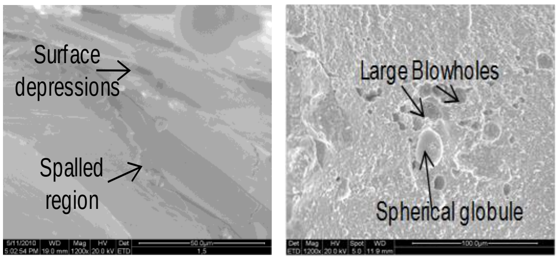
3.4 Comparative analysis of machined surface topography

In the analysis of quality of machined surfaces, an assessment of surface topography was performed for dry ED machined samples that correspond to the best conditions of MRR (see Figs. 6 *a-b*). The studies are done for dry EDMed surfaces using helium and oxygen at various magnifications (80X, 300X, 600X, 1200X, and 2400X).



a. *b.*

Fig. 6 *a-b* Topography of dry EDMed surfaces using *a*. helium, and *b*. oxygen at the parametric conditions (50 V, 18 A, 22 μs, 0.15 MPa, 300 rpm, 5 mm)



a. *b.*

Fig. 7 *a-b* Topography of dry EDMed surfaces using *a*. helium, and *b*. oxygen at the parametric conditions (80 V, 12 A, 22 μs, 0.25 MPa, 100 rpm, 5 mm)

In general, the morphology of dry EDMed surfaces using helium gas is relatively better than those machined using oxygen gas (Figs. 6 *a-b* and 7 *a-b*). The machined surfaces using helium were comparatively evener. Further, the features indicating entrapment of gases (porosities, blowholes), thermal residual stresses (micro-cracks), melting and redeposition of work material (globular depositions, folding), non-uniform material removal (dimples) are much lesser on machined surfaces using helium. Thus, application of helium gas helps reduce the number of cracks on dry EDMed surfaces.

4. CONCLUSIONS

Experimental studies on new methods for improving productivity and machined surface quality in dry EDM, are presented in this paper. The following conclusions can be drawn:

- Statistical analysis of results of experiments with peripheral slots on electrode show that MRR is controlled by voltage (*V*), current (*I*), pulse off-time (T_{off}) and speed (*N*).
- The use of slotted electrodes in dry EDM reduces the TWR and the occurrence of debris attachment on the tool electrodes.
- The MRR obtained in dry EDM using He gas dielectric was 20 to 60 times lower than that in the case of using O_2 gas dielectric.
- In the dry EDM using helium, the speed of rotation (*N*) is the major contributor to an increase in MRR than the current (*I*).
- Observation of topography of dry EDMed surfaces shows that the use of helium gas dielectric causes formation of lower number of micro-cracks than that of with the use of oxygen as dielectric.

ACKNOWLEDGEMENT

The authors wish to acknowledge Department of Science and Technology, Government of India for providing funding for this work. We also thank our collaborator, M/S Electronica Machine Tools, Pune for providing technical support to this work.

REFERENCES

[1] **Kunieda, M., Yoshida, M., Taniguchi, N.** (1997), "*Electrical discharge machining in gas*", CIRP Annals - Manufacturing Technology, v46, n1, pp. 143-146.

[2] **Tao, J., Shih, A. J., Ni, J.** (2008), "*Experimental study of the dry and near dry electrical discharge milling processes*", Journal of Manufacturing Science and Engineering,v130, pp. 1-8.

[3] **Govindan, P. and Joshi, S.S.** (2010), "*Experimental characterization of material removal in dry electrical discharge drilling*", International Journal of Machine Tools and Manufacture, v50, n5, pp. 431-443.

[4] **Kunieda, M., Lauwers, B., Rajurkar, K. P**., **Schumacher, B. M**. (2005), "*Advancing EDM through fundamental insight into the process*", CIRP Annals – Manufacturing Technology, v54, n2, pp. 64-87.

[5] **Zhang, Q. H., Zhang, J. H., Ren, S. F., Deng, J. X., Ai, X.** (2004), "*Study on technology of ultrasonic vibration aided electrical discharge machining in gas*", Journal of Materials Processing Technology, v 149, n1-3, pp. 640-644.

[6] **Puranik, M. S. and Joshi, S. S.** (2008), "*Analysis of accuracy of high-aspect ratio holes generated using micro-EDM Drilling*", Proceedings of the Institution of Mechanical Engineers, Part B, Journal of Engineering Manufacture, v222, n11, pp.1453-1464.

[7] **Phadke, M.S**., "*Quality Engineering using Robust Design*", Prentice Hall Publication, New Jersey, 1989.