Macro Scale Arrayed Structure Fabrication using Reverse EDM

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Abstract: In the last few years, industries have been facing challenges to fabricate the complex shaped geometries and arrayed structures on difficult to cut materials. Recently, various researchers have successfully applied reverse electro-discharge machining (R-EDM) process for manufacturing of the arrayed structures at micro-level. In this paper an attempt has been made to check the feasibility of R-EDM for manufacturing the arrayed structure at macro-level and used it as a tool electrode in normal EDM. Effects of process variables like-pulse current, gap voltage and pulse ON time are analyzed through the variation of material removal rate (MRR), tool wear rate (TWR) and surface roughness. Discharge current found to be an influential parameter which affects the MRR and TWR severely in both variants of EDM i.e. R-EDM and normal EDM.

Keywords: ***EDM, R-EDM, arrayed structures, MRR, TWR***

1 Introduction

It is difficult to find tool material which is sufficiently hard and strong to cut the advanced materials. Production of complex shapes with better surface finish, precise tolerances and higher production rates in such materials by conventional methods is even more difficult. Non-conventional machining processes can be used to machine the parts required in aerospace, nuclear chemical industries. Some of them can be used only for electrically conductive materials, while others can be used for both electrically conductive and non-conductive materials. In non-conventional machining methods, there is no direct contact between the tool and the work piece; hence the tool need not be harder than the workpiece [1].

EDM is one of the well-established non-conventional machining processes which have been widely used in modern metal working industry. In EDM, electrical conductive metals with sufficient toughness and irrespective of its hardness can be manufactured by using shaped tools in the presence of dielectric fluid to produce complex cavities in dies and moulds, which are otherwise difficult to create by conventional machining processes [2]. The recent developments in the field of EDM have progressed due to the growing application of EDM process for machining of complex arrayed structures [3].

1.1 Reverse EDM

To replicate holes on a workpiece, positive terminal is connected to it and fed down against metallic plate which is being already machined. In reverse EDM (R-EDM) process, holes are created on a metallic plate by any conventional or non-conventional machining processes. So, region corresponds to holes are not machined and selective erosion results into fabrication of multiple electrodes at holes. R-EDM technique found to be a prominent alternative to fabricate multiple microelectrodes of various shapes [4]. Also existing processes like-Lithographie galvanoformung abformung (LIGA) and wire EDM (WEDM) have some inherent difficulties to produce high aspect ratio microelectrodes with predetermined accuracy level and are quite expensive [5]-[7]. An attempt has been made by Kim et al. to fabricate the three microelectrodes of diameter 35 µm and 1.5 mm length on tungsten carbide rod by R-EDM. They investigated the effect of voltage and capacitance on the R-EDM performance and suggested the optimum set of process parameters. Mastud et al. [5 2009] fabricated the high aspect-ratio micro-rod arrays (6x6, 16x16) having diameter of 60 µm and aspect ratio as high as 33 on brass rod. They identified the gap voltage and capacitance as the influential factors affecting the dimensional accuracy and erosion rate of micro-rods.

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Yi et al. [8] fabricated the high aspect-ratio shadow mask for organic thin film transistors (OTFTs) on stainless steel and achieved impressive productivity improvement by using batch mode µ-EDM. Zeng et al. [9] explored and assessed the ultrasonic vibration assisted µ-EDM as an alternative to LIGA for fabrication of micro-electrode array (3x3) of diameter 30 µm and observed theimprovement in surface finish and productivity. In another study by Zeng et al. [10] observed the reduction in machining time with the increase in voltage and capacitance. Hwang et al. [11] developed an efficient method to fabricate the micro pin array (40x40) having high hardness and high density by combining the vibration assisted mechanical peck drilling to drill micro-hole array and R-EDM to replicate these holes on workpiece. In order to achieve optimum results for R-EDM various flushing techniques for debris removal have been analysed. There are many process variables like current, voltage, capacitance, pulse ON time, flushing of dielectric fluid, threshold, plate thickness (mm), feature size etc. which directly affect the MRR, dimensional accuracy, surface finish, erosion rate and tool wear rate. Mastud et al. [12] have found that inter-electrode gap being an integral part of the EDM processes. They also observed that dimensions of fabricated micro-rods are always less than the initial diameter of micro-cavity on a tool electrode. A taper of range 1.5–3^o has been witnessed on the fabricated micro-rods, which varies with the selection of processing parameters during machining. Side wear of the cavity and non-uniform material removal during arcing are found responsible for the taper on fabricated structures. It is further observed that eliminating arcing using optimized process parameters, using low erosion tool materials, and adopting advanced flushing methods improves the dimensional accuracy of the process. It is also noted that the nature of sparking controls the crater size which governs the amplitude of surface roughness that is mainly influenced by electrical parameters. The surface roughness on the fabricated electrode by micro R-EDM varies between 0.3-2.7 µm R_a. The root portion of the rod is found smoother compared to its tip which covers deposited carbon on it [13, 14].In order to obtain such complex shape first it is required to fabricate the tool having exact replica of that shape. This shortcoming of EDM leads to the use of R-EDM. In R-EDM, such complex shapes can be imparted on tool easily and with accuracy if parameters are controlled. Further the studies in R-EDM for generating array of macro-features is not adequate and lacks understanding. In view of this the present paper attempted to machine structured array of geometry on AISI D2 hard steel for accuracy assessment.

2 Experimental Work

The experiments are planned to analyze the MRR, Tool Wear Rate (TWR), and surface roughness and dimensional accuracy in R-EDM process. The experimental procedure followed is shown in Fig.1

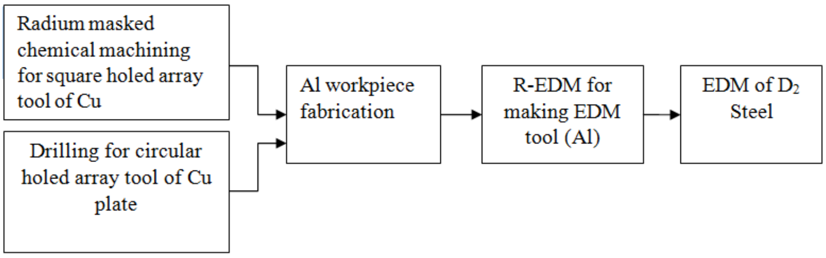


Fig. 1. Experimental Theme

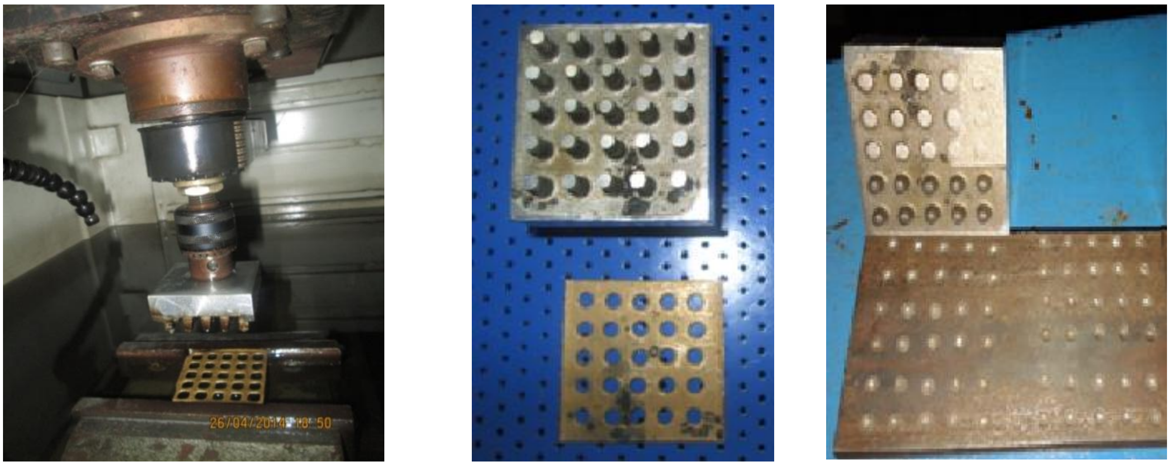
The input parameters selected are: Pulse Current (I_p), Gap Voltage (V_g) and Pulse on-time (T_{ON}) whereas MRR, TWR and Surface Roughness (R_a) are the response variables chosen to study the processes. The experimental conditions are summarized in Table 1 whereas properties of dielectric fluid are shown in Table 2.

Table 1 Experimental conditions

Sr. No.	Process Parameter	Levels
1	Pulse Current, I_p (A)	10, 15, 20, 25
2	Gap Voltage, V_g (V)	60, 70, 80
3	Pulse ON Time, T_{ON} (µs)	50, 75, 100
4	Workpiece Material: Aluminium (R-EDM) AISI D2 tool steel (EDM)	
5	Tool Material: Copper(R-EDM) Aluminium (EDM)	
6	Dielectric Fluid (DEF-92 Grade)	

Table 2 Properties of DEF-92

Property	Specification
Color	Crystal Clear
Odor	Odorless
Specific Gravity	0.78 +/- 0.02
Flash Point	1050 +/- 20°C
Viscosity	2.16 Pa.S
Dielectric Strength	45 K.V



(a) (b) (c)

Fig. 2. (a) Experimental setup for R-EDM (b) workpiece and tool electrode after R-EDM and (c) workpiece and tool electrode after EDM

3 Results and Discussion

3.1 Analysis of Response Variables in R-EDM

Table 3 presents the result obtained during the experiments.

Table 3 Results of R-EDM Process

Expt. No.	Input Parameter			MRR (g/min)	Surface Roughness, R_a (µm)	TWR (g/min)
	I_p (A)	T_{ON} (µs)	V_g (V)			
1	20	100	90	0.1678	10.1	0.11733×10^{-3}
2	15	100	90	0.1065	7.84	0.08799×10^{-3}
3	10	100	90	0.05246	5.9	0.05866×10^{-3}
4	25	100	90	0.1795	12.09	0.14667×10^{-3}
5	25	75	90	0.1667	10.19	0.13823×10^{-3}
6	25	50	90	0.1562	9.37	0.12987×10^{-3}
7	20	100	80	0.15	11.63	0.11698×10^{-3}
8	20	100	70	0.15143	8.53	0.11738×10^{-3}
9	20	100	60	0.15235	6.43	0.11824×10^{-3}

A. Analysis of MRR

Fig. 3 shows the effect of input parameters MRR. It is found that MRR is mainly influenced by discharge current. As the discharge current increases the energy transformed from the tool electrode to the workpiece increases, so the amount of material removed goes on increasing as shown. Higher MRR can be achieved by increasing current. Further as T_{ON} increases, the amount of energy transferred to the workpiece increases. T_{ON} decides the duration of sparking, so as the T_{ON} increases MRR goes on increased. In the case of effect of gap voltage, the increase in MRR with decrease in gap voltage is seen but the variation is almost negligible as compared to other process parameters so it has very less influence.

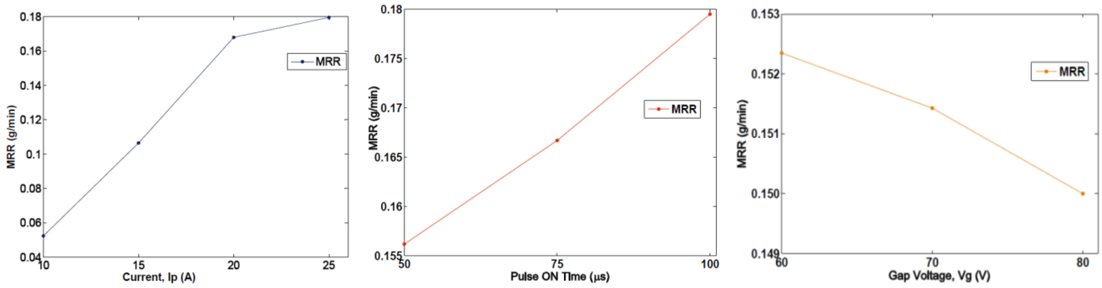


Fig. 3. Effect of process parameters on MRR in R-EDM

B. Analysis of TWR

It can be analyzed by Fig. 4 that the tools wear increases at high level of current. Tool wear is directly proportional to the discharge current i.e. the energy transformed from the tool electrode to the workpiece increases and varies linearly. It is found that as TON increases, TWR also increases because energy transformation takes place for longer duration still it is not influenced by TON to a greater extent. Further increase in tool wear with decrease in gap voltage is noted. The variation in tool wear rate with respect to change in gap voltage is almost negligible.

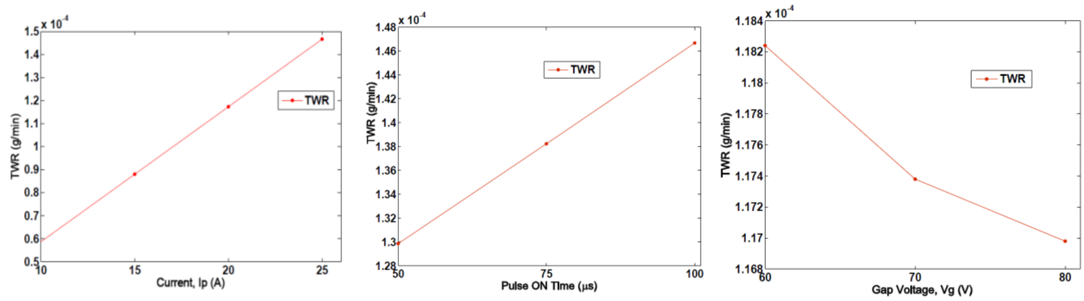


Fig. 4. Effect of process parameters on TWR in R-EDM

C. Analysis of Surface Roughness

As stated earlier, as the amount of discharge current directly affects the MRR, due to increase in the energy density at discharge gap the crater produced are deep and wide. So the surface produced at the high discharge current is rough as compared to the surfaces produced at the low discharge current. These in turn produce high machining rate at the high discharge current but compensated by losing the surface quality. T_{ON} has less effect as compare to that of discharge current on the surface roughness as shown in Fig. 5. On the other hand when T_{ON} increases, the time available for the flushing of the debris i.e. T_{OFF} reduces, hence the value of the surface roughness increased.Surface finish increases with decrease in gap voltage. Fig. 5 shows that as the discharge voltage increases, the energy transformation increases so the value of surface roughness increases.

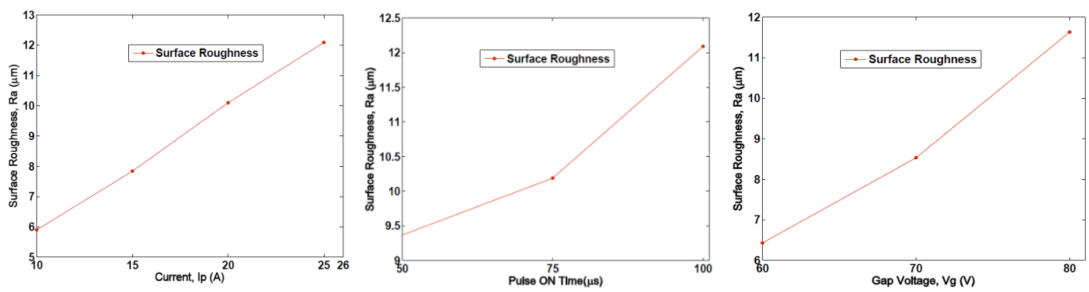


Fig. 5. Effect of process parameters on surface roughness in R-EDM

3.2 Application of R-EDM electrode

Table 4 indicates the results obtained during normal EDM process.

Table 4 Results of Conventional EDM Process

Sr. No.	Input Parameter			MRR (g/min)	TWR (g/min)
	I_p (A)	T_{ON} (µs)	V_g (V)		
1	20	100	90	0.40143	0.025
2	15	100	90	0.2353	0.01764
3	10	100	90	0.18182	0.01618
4	25	100	90	0.5	0.03571
5	25	75	90	0.375	0.03325
6	25	50	90	0.168	0.0305
7	20	100	80	0.2756	0.0137
8	20	100	70	0.2857	0.01428
9	20	100	60	0.2875	0.025

A. Analysis of MRR

It can be analyzed from Fig. 6 that there is increase in MRR with increase in discharge current because of increase in discharge energy delivered from tool to workpiece. Also there is increase in MRR with increase in pulse on time because of increase in the duration of discharging energy. Gap voltage has very less influence on MRR.

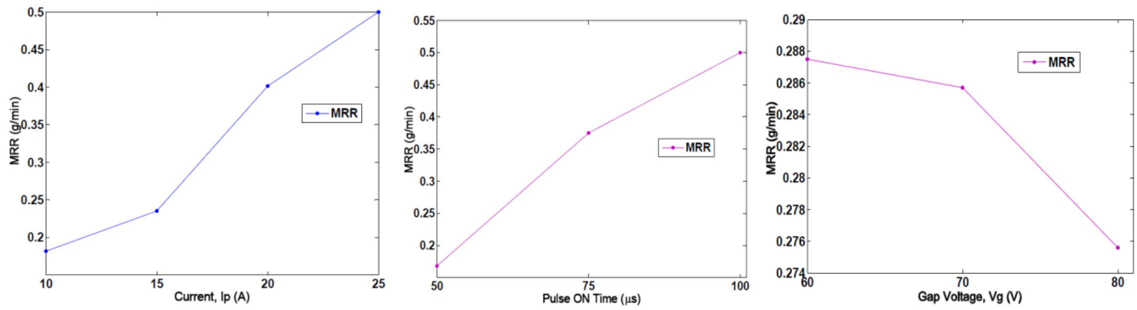


Fig. 6. Effect of process parameters on MRR in EDM

B. Analysis of TWR

It can be observed from Fig. 7 that tool wear increases with increase in the discharge current as tool wear is proportional to the discharge current. Also tool wear increases with increase in T_{ON} because of increase in duration of discharging energy. There is decrease in tool wear with increase in gap voltage as observed similarly in case of R-EDM.

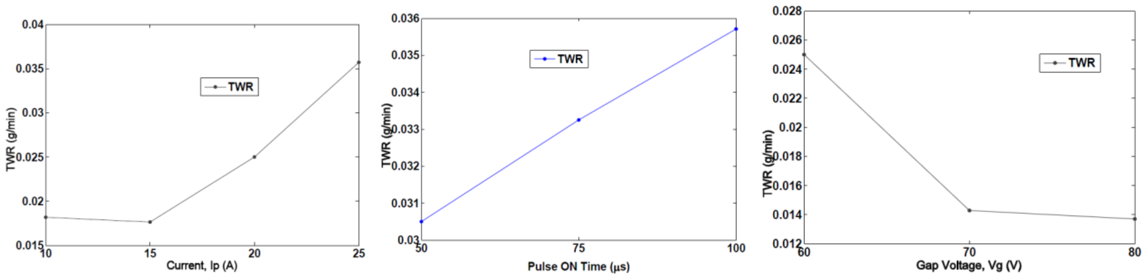


Fig. 7. Effect of process parameters on TWR in EDM

4 Conclusions

The aim of the work carried out is to check the feasibility of R-EDM on macro scale.

- MRR and TWR are mainly influenced by discharge current. Higher the value of current, higher will be the MRR and TWR.
- Electrode material should be such that it would not undergo much tool wear when it is impinged by positive ions. Copper has lower tool wear rate as compare with aluminium. Tool wear is mainly the function of discharge current and melting point of the material.
- R-EDM appears to be a better variant as it facilitates debris flushing due to gravity.

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