Performance Evaluation of Different Electrode Geometries in Electric Discharge Drilling of MMCs

Sabindra Kachhap and Abhishek Singh
Department of Mechanical Engineering, National Institute of Technology Patna, Patna -800005, India
Email: sabindra08me@nitp.ac.in, abhishek.singh@nitp.ac.in

Sanoj Kumar
Bharat Electronics Limited, Sahibabad Industrial Area, Bharat Nagar, Ghaziabad - 201010 (UP), India.
Email: sanojkumarrai@gmail.com

***Abstract*—Electric discharge drilling (EDD) is a hybrid machining process, which has been assembled with Z axis numerical control electric discharge machining (ZNC-EDM) setup. EDD process is basically a hole making process used for electrical conductive materials such as super alloys, metal matrix composites (MMCs) etc. It is difficult to machine these materials. The present discussion will attempt to highlight the recent developments in the field of drilling of MMCs. In this study, electric discharge drilling has been carried out on MMC. Al based MMC (Al6063/10%SiC) is used as a workpiece material and copper is used as an electrode tool material. Five different electrode geometries viz. conical, solid slotted, hollow, hemispherical and hollow slotted tool have been used for comparative analysis on machining. The effect of input variables such as discharge current, pulse on time, pulse off time, tool speed of the output responses such as material removal rate (MRR) and tool wear rate (TWR) during the machining of MMC were investigated. Some other constant parameters were also used such as flushing pressure, spark gap and voltage gap etc.**

***Index Terms*—Electric discharge machining (EDM), Electric discharge drilling (EDD), Tool geometries, MRR, TWR**

I. Introduction

Electric discharge drilling (EDD) is basically a combination of two processes, electric discharge machining and conventional drilling process. EDD provides a means to create a high efficiency hole on MMC's with minimum machining time, hence this method facilitates the productivity of the process and at the same time it maintains the surface integrity of the work specimen. The technological improvement of manufacturing attribute can be achieved by high efficiency of EDD process. Singh et al. [1] worked on optimization of different process parameters such as MRR and TWR of MMCs and also compared the feasibility of EDM and EDD process. Gatto et al. [2] worked on the bridges of debris formed during EDD of a ceramic composite and also found that the material removal takes place by melting and evaporation. This is mostly hollow and occupied much higher volume than the machine one. Sony et al. [3] analyzed the effect of rotation of electrode tool on the EDM of titanium alloy and also observed that the rotary motion of tool increases the MRR and TWR for all levels of current and pulse on time. Govindan et al. [4] has investigated the performance of dry EDM using slotted electrode and observed the optimum value of the response variable (Maximum MRR, Minimum TWR). Wang et al. [5] found that in case of rotary EDM process, the main problem is of using a disk like electrode for machining of Al6061/Al_2O_3 composites. Yan et al. [6] investigated the relevance of machining of Al 6061/Al_2O_3 composite materials by the EDM process for blind hole drilling and obtained the MRR and TWR with various input parameters. Mohan et al. [7] worked on the EDM of Al-SiC metal matrix composite using rotary tube electrode and found that EDM drilling with rotating tube electrode has produced higher MRR than the rotating solid electrode. Munz et al. [8] worked on EDD of conductive ZTA-TiC composites and found that a variation of discharge current, discharge time, pulse shape, and flushing conditions has a strong influence on machining parameter and hence on machining quality. Kumar et al. [9] worked on EDD of hybrid MMC and correlate the effect of input variables such as current, tool speed, duty factor, and flushing pressure on the MRR and TWR. Daneshmand et al. [10] observed the effect of tool rotation and Al_2O_3 powder in powder mixed-EDM along with the input parameters on MRR and TWR.

The objective of this paper is to evaluate the effect of tool geometries with variation of discharge current, pulse on time, pulse off time and tool speed on MRR and TWR in the machining of MMCs.

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II. Experimental Procedure

All the compulsory experiments were conducted on Z-CNC EDM machine supplied by Electronica India Limited, Pune, India. To produce rotational speed of tool electrode, an experimental setup was installed on the servo head of EMD machine by detaching the actual tool holder.

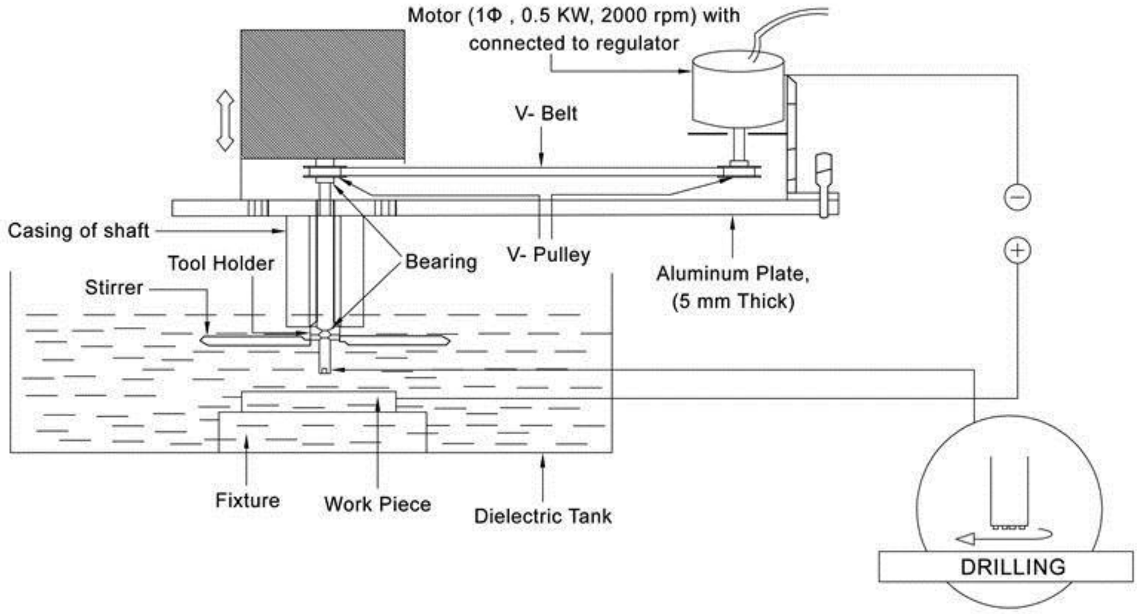

Figure 1. Schematic diagram of electric discharge drilling setup.

A schematic diagram of installed EDD setup is shown in Fig. 1. Al6063/10%SiC MMC was chosen as the workpiece material of dimensions 80x45x6 mm and five different shaped copper tool electrodes length of 70 mm diameter. The conical shape tool diameter is 10 mm, solid slotted tool of outer diameter is 10 mm, inner diameter is 5 mm and has 1mm slots. Hollow tool outer diameter is 10 mm and inner diameter is 5 mm. Hemispherical tool of base diameter 10 mm and hollow slotted tool outer diameter is 10 mm, inner diameter is 5 mm and has 1 mm slots. Calculate MRR and TWR from Equation (1) and (2).

$$\text{MRR (mm}^3\text{/min)} = \frac{W_{iv} - W_{fv}}{T_m \times \delta} \times 1000 \quad (1)$$

$$\text{TWR (mm}^3\text{/min)} = \frac{T_{iv} - T_{fv}}{T_m \times \delta} \times 1000 \quad (2)$$

Where W_{iv} is the initial volume of the workpiece, W_{fv} is the final volume of the workpiece, Tm is the machining time, δ is density of the material, T_{iv} is the initial volume of the tool electrode, T_{fv} is the final volume of the tool electrode. Table 1 and Table 2 show, the range of input parameter and constant parameter, respectively.

TABLE I. Process Parameters and Their Limits

Discharge current (amp)	Pulse on time (µs)	Pulse off time (µs)	Tool speed (rpm)
6-30	60-500	8-90	400-1200

TABLE II. Constant Machining Condition for Experiments

Discharge current (amp)	Pulse on time (µs)	Pulse off time (µs)	Tool speed (rpm)
12	200	45	750

III. Results and Discussion

There are various tool geometries used for machining on which different set of experiments were conducted one by one to find out the geometry which gives maximum MRR and minimum TWR. For the experiments constant machining conditions i.e. discharge current of 12 amp, duty factor 0.82, tool rpm 750 and flushing pressure of 0.25 gm/cm^3 is required. Different values of MRR and TWR are obtained by varying tool geometries shown in Table 3.

It has been observed that discharge current has a dominating effect on MRR. During the EDD process, expansion of plasma takes place. At the same time localized temperature is abruptly raised beyond the melting point of work material causing quick melting of material removal rate [11]. As per Fig. 2 (a) MRR shows an increasing trend with discharge current directly influence TWR. The trend of the curve (Fig. 2 (b)) shows that large value of discharge current yields excessive tool wear rate and this may be because of high thermal conductivity of copper tool.

TABLE III. EXPERIMENTAL RESULTS OBTAINED FOR DIFFERENT TOOL GEOMETRY DURING THE EDD PROCESS

Tool geometry	Conical	Solid slotted	Hollow	Hemispherical	Hollow slotted
Cross section					
MRR (mm^3/min)	77.824	75.157	95.736	68.734	103.989
TWR (mm^3/min)	0.131	0.126	0.161	0.131	0.175

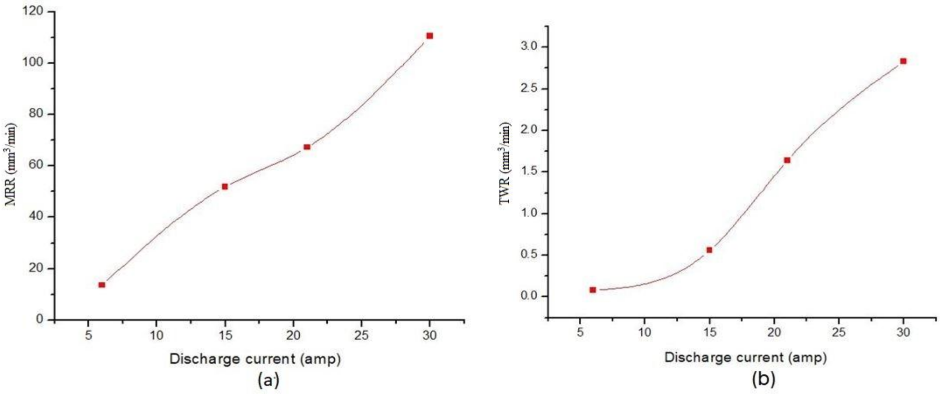

Figure 2. Graph plot between discharge current vs. MRR and TWR respectively.

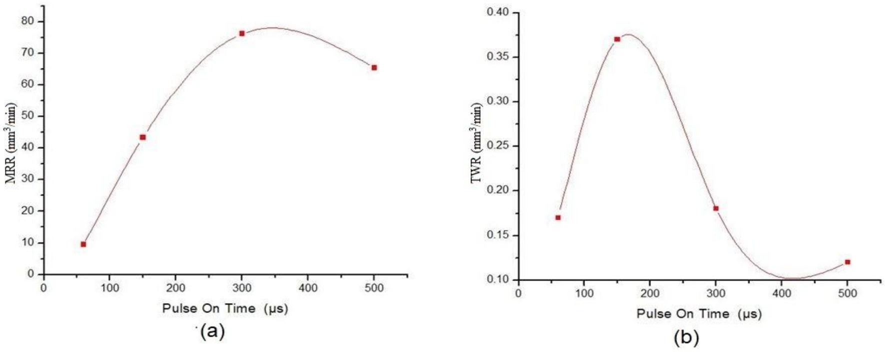

Figure 3. Graph plot between pulse on time vs. MRR and TWR respectively.

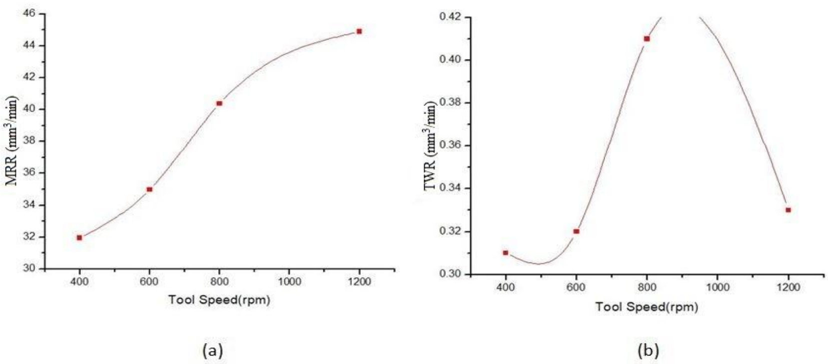

Figure 4. Graph plot between tool speed vs. MRR and TWR respectively.

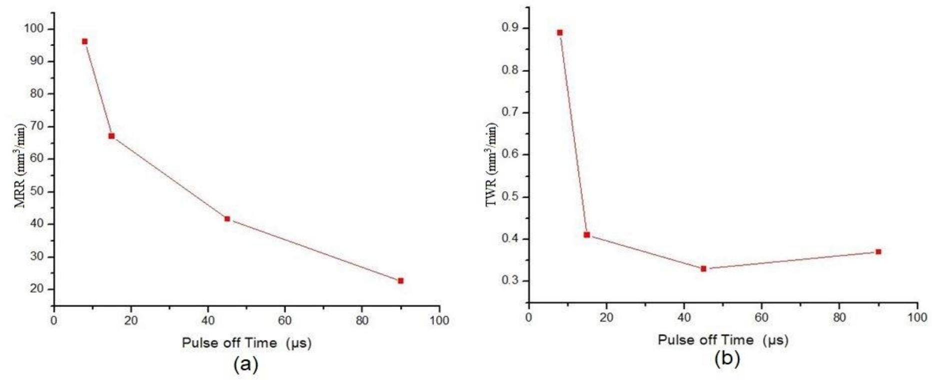

Figure 5. Graph plot between pulse off time vs. MRR and TWR respectively.

It is well known fact that an increase in discharge duration will increase the MRR as pulse on time is directly proposal to spark energy, i.e. higher the pulse on time, higher is the MRR value because greater time is available for heat transfer. Although when pulse on time increases upto the optimum values, it will not further increase MRR value because sparking becomes insensitive for possible rise of MRR [10]. The behavior of MRR with respect to Pulse on time can be observed from Fig. 3 (a). TWR increases linearly or proportionally with an increase in pulse on time, but later on it shows decreasing trend (from Fig. 3(b)). The pulse on time increases initially TWR curve shows the increasing trend, but after 150 µs it will show decreasing trend because the spatial current density of discharge frequency decreases [12]. Tool speed imparts significant effect on MRR, as tool speed is directly linked with electrical spark and the degree of flushing [6]. When tool speed increases MRR will increase. But after a certain point MRR decrease with increases in the tool speed as shown in Fig. 4 (a). TWR remains almost constant for the period of 400 rpm to 600 rpm. It shows slightly decreasing trend beyond 800 rpm (can be observed from Fig. 4(b)) as at the higher value of tool speed, sparking becomes insensitive. Pulse off time has an opposite effect on MRR value, i.e. with increase in pulse off time MRR decreases as shown in Fig. 5 (a). As with increase in pulse off time, intensity of sparking decreases. Thus less time is available for possible transfer of heat. Tool wear function according to discharge current that if discharge current increases TWR increases considerably. Apart from discharge current, tool wear also function according to pulse on time and tool geometry [1]. TWR which is observed for the same input parameters for different geometries is plotted and represented as shown in Fig. 5 (b). TWR decreases with increase in pulse off time because it behaves reciprocally with pulse on time. So a trade-off has to be made between pulse on time and pulse off time so that maximum MRR is obtained with minimum TWR.

IV. Conclusion

An experimental approach is presented in this work to estimate MRR and TWR during the EDD process on MMC as a workpiece.

- A hybrid machining technique like EDD can be very efficient alternative in hole making process. It is difficult to machine materials like metal matrix composite.
- The MRR in EDD process is very high as compared to EDM process.
- The TWR in EDD process is also high in comparison to the conventional EDM process those it is not desirable at all.
- Geometry plays a key role to decide its performance of drilling operation during the EDD process. The performance can be judged from MRR value obtained using different geometries. Among all tool geometries, hollow slotted tool has highest MRR and TWR.
- MRR increases with increase in tool speed, but beyond 800 rpm it will show decreasing trend. While the variation of tool speeds have little influence on TWR. With the increase in speed beyond 800 rpm TWR slowly decrease.

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Sabindra Kachhap received M. Tech. degree From Department of Mechanical Engineering, NIT Patna, India, in 2013. He is currently a Research scholar in Department of Mechanical Engineering, NIT Patna, India. His research areas are hybrid machining, electric discharge machining, soft computing, and optimization.

Abhishek Singh received Ph.D. degree from IIT Roorkee, India in 2014. He is presently faculty in Department of Mechanical Engineering, NIT Patna. India, Research Interest:-Advanced and Hybrid Machining Processes, Machining of Advanced Materials, Processing and Characterization of Composite Materials, Metal Matrix Composites

Sanoj Kumar received M. Tech. degree From Department of Mechanical Engineering, NIT Patna, India, in 2015. He is doing job in Bharat Electronics Limited (BEL) India.