Parametric Investigations on Rotary Tool Near-dry Electric Discharge Machining

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Abstract

Electrical discharge machining (EDM) is an extensively used and widely accepted non-traditional machining process. Rotary tool near-dry EDM is a process variant of EDM process that utilizes two-phase dielectric medium instead of hydrocarbon oil. In the present investigation, drilling on high-speed steel by rotary tool near-dry EDM was performed. The effect of input parameters such as peak current, pulse on time, gas pressure and liquid flow rate on material removal rate was investigated. One factor at a time (OFAT) approach was used to perform the experiments. The combination of air and distilled water was used as a two-phase dielectric medium. The experimental results revealed that MRR increased with an increase in current, pulse on time and gas pressure. Rotation of the tool electrode reduces debris accumulation in the inter-electrode gap and debris deposition on the tool electrode. Tool rotation resulted in two to three times higher MRR than that of near-dry EDM without tool rotation and dry EDM processes. The surface quality achieved by rotary tool near-dry EDM was also better than that of near-dry EDM.

Keywords: Rotary tool near-dry EDM, Material Removal Rate (MRR), Two-phase Flow, Water-air.

1. INTRODUCTION:

Electric discharge machining is a well-established non-traditional machining process. It is commonly used to machine conductive materials regardless of their strength and hardness. In EDM, the material removal is caused by thermal energy generated by the spark discharges. The basic EDM configuration consists of various components such as tool electrodes, DC power supply unit and dielectric medium. Among them, the dielectric medium plays an important role to control the precision as well as the machining performance of EDM. Hydrocarbon oil and water are the commonly used dielectric medium in EDM. However, use of hydrocarbon oil as a dielectric generate toxic fumes, aerosols, odors. Also, the adhesion of carbon particles on the work surface, degradation of dielectric properties are the problem in conventional EDM. Decomposition of hydrocarbon oil produce harmful vapor such as CO and CH_4. Carbon content in the white layer is found and appeared as iron carbides when hydrocarbon oil is used as a dielectric [1]. Hydrocarbon oils are strong skin irritant and can cause contact dermatitis to skin when exposed frequently or for longer duration [2]. Due to scarcity of petroleum products, fire hazards, environmental concerns, increasing cost, and to increase the productivity, other EDM dielectric medium have been developed [3].

In order to overcome the above-mentioned problem associated with EDM in hydrocarbon oil, water-based dielectrics, chemical compound, solid metal particles mixed in dielectrics, gases, and combination of liquid and gaseous dielectric have been reported as an alternatives of hydrocarbon oils. Newer dielectrics were introduced with an objective to achieve higher MRR, better surface finish and environmental friendly machining. Modifications in dielectric medium, gap control strategies, tool design etc. were proposed to improve the EDM performance.

A large volume of literature expounds on use of water and water with additives as a dielectric medium in EDM. An early attempt in this connection was made by Jeswani in 1981 with an objective of possible increase in efficiency of conventional EDM [4]. Jeswani compared the performances of EDM on the basis of dielectric such as distilled water and kerosene over the range of 72-288 mJ. Jeswani reported that higher MRR and good surface finish was obtained due to increase in sparking frequency. Higher MRR was reported by Jilani and Pandey, Tang et al. when tap water was used as a dielectric as compared to distilled water and mixture of distilled and tap water [3, 5]. Higher power input and higher thermal stability can be achieved with aqueous dielectric. Aqueous dielectric medium have eight times higher specific boiling energy [6], more stable discharges and relatively smaller impulsive force [7] than that in hydrocarbon oil. A solution of high concentration of polyethylene glycol 600 was used as a dielectric and had a performance compatible with hydrocarbon oil [8]. Konig and Joerres (1987) investigated the aqueous solution of sugar, glycerine, glycol, polyethylene glycol 200, 400 as a dielectric medium. They found that the aqueous solution containing glycerin with 87% of concentration yielded higher MRR and lower tool wear rate [9]. Addition of urea in distilled water was used as a dielectric by Yan et al. in 2005 [10]. They experimentally investigated the influence of urea solution in distilled water on machining characteristics on Ti workpiece. The surface of Ti had been modified and smoother surface was obtained in urea solution as compared to water dielectric. Kunieda et al. (1991) supplied oxygen gas in IEG in water dielectric. The MRR was found to be increased due to high frequency and enlarged volume of discharge crater [11]. The distilled water is decomposed into oxygen and hydrogen. The released oxygen in distilled water increase the discharge stabilities which results in higher MRR.

To overcome the inadequacies of conventional EDM, new techniques were developed. New techniques includes EDM with gaseous dielectric (dry EDM), EDM with powder mixed in dielectric (powder mixed EDM) and EDM with two-phase dielectric (near-dry EDM) etc. The feasibility of use of the inert gases such as argon, nitrogen, and helium, as dielectric medium was investigated by NASA in 1985 [12]. Kunieda et al. (1997) developed a process variant of EDM by using a combination of different gases as dielectric medium. This process variant of EDM is called as dry EDM. Dry EDM is achieved in gas instead of hydrocarbon oil, so the pollution decreases. Higher MRR was achieved with oxygen gas as a dielectric medium. In the presence

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of oxygen in the inter-electrode gap (IEG), heat is liberated due to exothermic reaction [13]. Various methods were proposed to enhance the performance of the dry EDM. The proposed methods were ultrasonic assisted dry EDM, hybrid dry EDM in pulsating magnetic field, dry EDM in quasi-explosion mode and dry EDM with piezoelectric servo system. These proposed methods improved the debris flushing, MRR and lower the tool wear rate. However, dry EDM resulted in poor surface quality and accuracy due to the deposition of debris on the tool and work surface.

Near-dry EDM is a modification of conventional EDM and dry EDM. Near-dry EDM was developed by Tanumura et al. in 1989 [14] to overcome the problem of conventional and dry EDM. In near dry EDM, two-phase dielectric medium is used instead of single phase. The machining performance is also affected by type of dielectric medium and method of delivery [15]. The comparison of wet, dry and near-dry electric discharge drilling was carried out by Cao et al. (2007) in Al6061 sheet of 1.27 mm thickness [16]. The MRR in near dry EDM process is higher than wet and dry EDM and near dry EDM can produced nearly zero taper hole. During machining of AISI H13 tool steel, Tao et al. 2008 obtained mirror-like surface finish [15]. The effect of liquid flow rate, lead and tilt angles of the electrode on machining characteristics in near dry EDM milling process was investigated by Fujuki et al. (2009) [17]. A CFD model to predict the liquid flow rate was also developed. Fujiki et al. (2011) developed a gap control strategy for five-axis near-dry electric discharge milling and 30 % increase in MRR was reported [18]. Near-dry EDM process provides thinner recast layer even at higher discharge energies and 60 % higher MRR as compared to conventional EDM [19]. The dielectric medium with high viscosity and high Prandtl number yields more MRR. Glycerin-air dielectric medium resulted in higher MRR, fine surface integrity with no recast layer as compared water-air and EDM oil-air mixtures as a dielectric medium [20].

In this paper, the rotary tool near-dry EDM drilling on the self-developed setup with the water-air dielectric medium is investigated to understand the effect of process parameters. The peak current, pulse on time, gas pressure and liquid flow rate were investigated on machining performance in terms of MRR. The experimental procedure followed by results and discussion were presented in the subsequent section.

2. MATERIALS AND METHODS

The experiments were performed on an EMS 5030 die-sinking electrical discharge machine. A self-designed and developed attachment was attached to the existing EDM. This attachment consists of misting unit and the rotary unit. Misting unit regulates the two-phase flow of dielectric medium and rotary unit provides rotary motion to tool electrode. The misting unit, consist of air-compressor, precision pump, gas filter and pressure gauge. The precision pump was used to supply a controlled amount of liquid dielectric (distilled water). Air-compressor was used to supply the compressed air and the gas pressure was controlled by the compressor regulating valve. The rotary unit consists of an electric motor, belt and pulley drive. Belt and pulley drive transmits the rotational motion from the electric motor to the tool electrode. The workpiece was clamped in a vice attached to the machine table. The experimental setup is shown in Fig. 1.

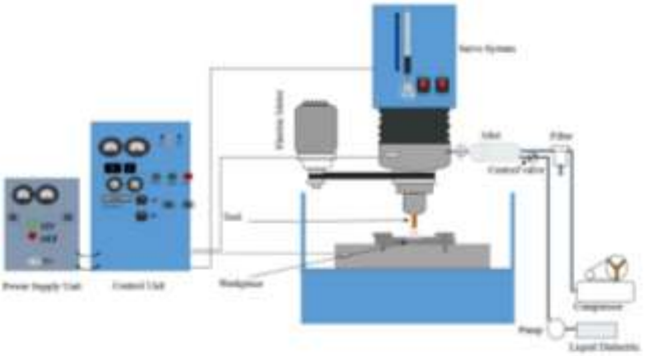

Fig. 1. Schematic of rotary tool near dry EDM set up

The tool electrode was tubular in shape with the outer and inner diameters of 6 and 3 mm, respectively. The length of the tool electrode was 40 mm through which mist was supplied in the IEG. High-speed steel (T2 grade) and 99 % pure copper were used as workpiece and tool electrode materials, respectively. The workpiece material was a plate with dimension 120 mm × 50 mm × 8 mm. The surface of work material used for experimentation was smooth and polished.

In this investigation, MRR was used to evaluate the performance of rotary tool near-dry. Electronic balance model: SHIMADZU AUW220D with a least count of 0.01 mg was used to measure the weight of the workpiece before and after each experiments. The MRR was calculated by equation (1).

$$\mathrm{MRR} = \frac{\Delta \mathrm{W}}{\rho \times T_m} \qquad (1)$$

Where ΔW is weight difference before and after machining in gm. ρ is the density of the work material in gm/mm^3. Tm is the machining time of each experiment in min.One factor at a time (OFAT) was used to perform the experiments. Peak current, pulse on time, gas pressure and liquid flow rate were selected as input parameters based on literature review and pilot experimentation. The rotation speed of tool electrode was fixed at 1000 rpm. Because during pilot experimentation the material removal rate was not much affected by increasing tool rotation speed above 1000 rpm. The variable and constant parameters used for experimentation are listed in Table 1.

Table 1: Experimental settings

Variable parameters	
Current (A):	3, 6, 9, 12 and 15
Pulse on time (μs):	190, 240, 290, 340 & 390
Liquid flow rate (ml/min):	3.2, 4.8, 6.4, 8.0 and 9.6
Gas pressure (psi):	10, 20, 30, 40 and 50
Constant parameters	
Tool rotation speed:	1000 rpm
Work material:	HSS
Polarity:	Straight (tool negative)
Dielectric Medium:	Distilled water-air
Tool material:	Copper
Lift:	4
Gap control:	3
Sensitivity:	3

3. RESULTS AND DISCUSSIONS

The rotary tool near dry electric discharge drilling was performed on HSS work material as per the experimental settings given in Table 1. The effect of various input process parameters on rotary tool near dry EDM on MRR are presented in Fig. 2-5.

3.1. The effect of peak current on MRR

The effect of peak current on MRR is presented in Fig. 2. From Fig. 2 it can be clearly seen that the MRR increased continuously by increasing the peak current. This was attributed to the fact that the discharge energy in IEG increased by increasing the current. The increased discharge energy resulted in more material melting of the work material in the molten puddle and thus, MRR increased. This finding was agreed with Tao et al 2008 [15] and Dhakar and Dvivedi 2016 [19].

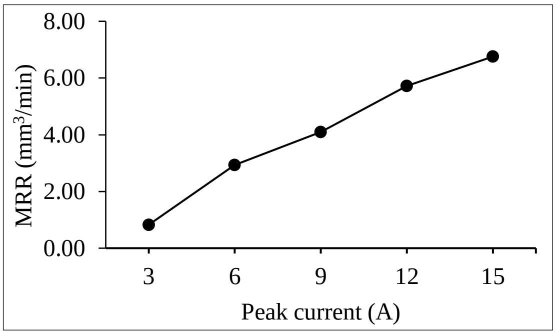

Fig. 2. Effect of peak current on MRR

3.2. The effect of pulse on time on MRR

The effect of pulse on time on MRR is shown in Fig. 3. From Fig. 3 it can be observed that with an increase in pulse on time, MRR increased continuously. The duration for energy transfer in each pulse increased by increasing the pulse on time. Due to which higher discharge energy per pulse transferred from tool electrode to workpiece. The higher energy led to the melting and vaporation of more material from the molten puddle. Thus, Thermal energy is available for a longer duration in the IEG, which resulted in increased MRR. This finding was concurs with Chen and Mahadivian 2000 [21].

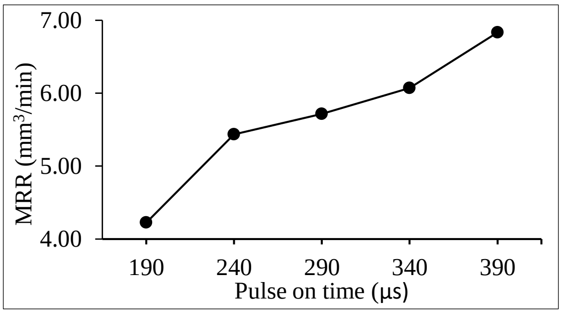

Fig. 3. Effect of pulse on time on MRR

3.3. The effect of gas pressure on MRR

An increase in gas pressure from 10 to 40 psi, steep rise in MRR was observed as shown in Fig. 4. After that, the MRR increased marginally. By increasing, gas pressure increased the heat dissipation rate and effectively cool the debris particles. Thus, the debris particles in the IEG flushed out effectively and reduced debris deposition on the machined surface leading to effective sparking. Due to which the concentrated thermal energy was transferred from the cathode to anode. As a result of that higher MRR was obtained.

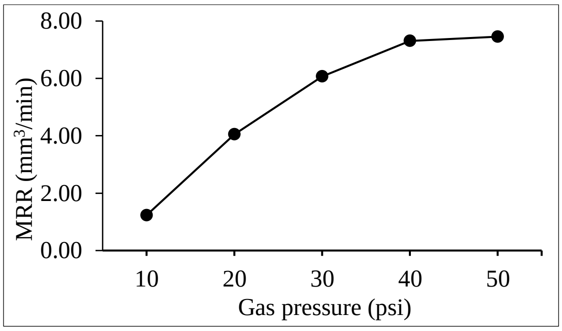

Fig. 4. Effect of gas pressure on MRR

3.4. The effect of liquid flow rate on MRR

The liquid flow rate is the amount of distilled water that is supplied in controlled manner and mixed with air to form mist. The effect of liquid flow rate on MRR is illustrated in Fig. 5. It can be observed from Fig. 5 that on increasing the liquid flow rate from 3.2 to 6.4 ml/min, MRR increased and then decreased. The number of liquid (distilled water) molecules into the IEG increased by increasing the liquid flow rate. More number of water molecules increase the cooling rate which results in earlier solidification of the debris particle. Due to which the deposition of molten material on the tool and work surface reduced. Which results in higher MRR because of effective flushing of debris from the IEG. At higher liquid flow rate above 6.4 ml/min the MRR decreased. It can be attributed that at higher liquid flow rate, water does not atomize properly and fills the gap between the IEG because of large amount of liquid in the air. The IEG changes frequently and reduced the MRR.

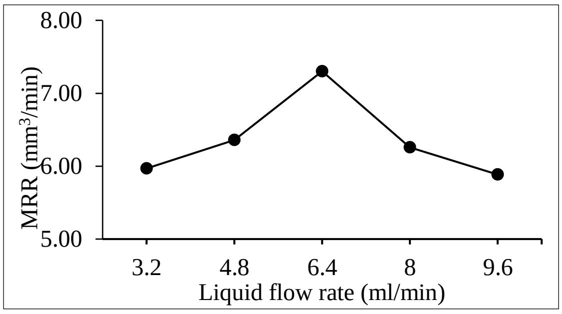

Fig. 5. Effect of liquid flow rate on MRR

4. CONCLUSIONS

In the present research work, rotary tool near-dry electric discharge drilling was carried out on HSS workpiece. The effect of peak current, pulse on time, gas pressure and liquid flow rate on the material removal rate was investigated. The MRR increased with an increase in current, pulse on time and gas pressure. Higher MRR was obtained at liquid flow rate 6.4 ml/min. Additionally, in rotary tool near-dry EDM the debris reattachment on the tool electrode and work surface was negligible due to increase in heat dissipation rate and effective flushing.

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