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Experimental investigations to evaluate the effect of magnetic field on the performance of air and argon gas assisted EDM processes

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ABSTRACT

The present paper focuses on the machining characteristics of EDM using the combined assistance of magnetic field and liquid-cum-gaseous dielectric namely, Magnetic Field – Air-Assisted EDM (MF-AAEDM) and Magnetic Field – Argon Gas Assisted EDM (MF-AGAEDM). The experimentation was carried out based on the central composite design to investigate the effect of peak current, pulse duration, duty cycle, magnetic flux density and air/gas pressure. The outcomes of two different processing condition have been compared to understand the effect of these parameters on material removal rate and electrode wear rate. The result shows the magnetic field increased both the material removal rate by 21–41% and electrode wear rate by 7–14% in EDM using liquid-air mixed dielectric. The exothermic reaction between air and work material increased the MRR by 10–18% in MF-AAEDM and the inert nature of argon gas reduced the EWR by 7–16% in MF-AGAEDM. The multi-objective optimization using genetic algorithm has also been performed in MF-AAEDM and MF-AGAEDM to obtain the optimum process parameters for maximum material removal rate and minimum electrode wear rate.

1. Introduction

Advancement in various technological fields demands the development of most efficacious processes that can machine the advanced category of materials and also offers the superior product quality. Materials such as tool steel, metal matrix composites and ceramics are mainly used in the field of aerospace, defense, die molding, medical and automobile industries. High strength, high hardness and high wear resistance properties of these materials make them difficult to cut through conventional route of machining. Electrical discharge machining (EDM) is an unconventional process, widely used for cutting difficult-to-machine materials. In EDM, an electrical discharge is produced between the electrode and work material and is separated by the dielectric fluid. Shankar et al. [1] reported 8000–12000 °C temperature of plasma for heating, melting and vaporizing the material in the localized spot on the surface of electrode and workpiece. However, the process is slow as compared to traditional machining processes. The intense heat of plasma damages the machined surface integrity and electrode geometry. These drawbacks of EDM limits its application in the manufacturing industries. Improvement in the process performance always remains the key domain of research in EDM. In last decade, several modifications in EDM has been done to make the process more efficacious. Air/gas assisted EDM, ultrasonic assisted EDM, EDM with cryogenic cooled workpiece/electrode and magnetic field assisted EDM are the modifications in EDM.

Kunieda and Furuoya [2] supplied air and oxygen gas through a tubular electrode to machine S45C steel in EDM process. The exothermic reaction was reported when oxygen and air were used during machining. The extra heat produced by the reaction was utilized in erosion process. The MRR was found to be higher in the air and oxygen gas assisted EDM as compared to EDM using liquid dielectric. However, it was observed that the removed material in the form of debris was deposited on the tube surface. Zhang et al. [3] used ultrasonic vibration in dry EDM during machining of C45 steel. The ultrasonic vibration reduced the debris attachment on the electrode surface and enhanced the Material Removal Rate (MRR). However, high setup cost and lack of knowledge in horn design limit the practice of ultrasonic vibration in EDM. Tao et al. [4] used the liquid-gas mixture as a dielectric in EDM. The air, nitrogen, oxygen and helium gases were used in the experimentation. The helium and nitrogen gases provided better surface finish as compared to air and oxygen. Moreover, high MRR was observed when oxygen gas was used. Liqing and Yingjie [5] mixed air, nitrogen and argon gas with oxygen gas in dry EDM to machine the cryogenically cooled workpiece. It was reported that the MRR increased by more than 200% while using oxygen and other gas mixture as compared to the non-oxygen gas mixtures. The cryogenic cooling improved the surface finish in the dry EDM process. However, the use of cryogenic fluid increases the process cost in the slow process like EDM.

In EDM, the electrode surface and geometry damage during

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machining. The damage in the electrode attributed to positive wear and negative wear. In the positive electrode wear, the loss of material takes place from electrode surface in the form of tiny craters. The positive wear occurs due to low melting temperature and low thermal conductivity of electrode material. It was commonly observed while using liquid dielectric in EDM [6]. The negative electrode wear occurs due to debris deposition on electrode surface [7] resulted in an increase in weight of the electrode after machining. The low thermal conductivity of dielectric caused the debris deposition on electrode surface [4]. An inefficient flushing condition also increases the tendency of debris deposition. Hence, in the negative electrode wear, the weight of electrode increases after the process. Both types of wear reduce the geometrical accuracy and surface quality of machined parts. Some investigations were conducted to minimize the electrode wear [8,9]. Srivastava and Pandey [10] observed that the Electrode Wear Rate (EWR) reduced by applying the ultrasonic vibration and cryogenic cooling to the electrode in EDM. Singh et al. [11] reduced the electrode wear ratio with the help of supplying compressed air through the electrode in Air Assisted EDM (AAEDM). The reported reason for the reduction in electrode wear ratio was the cooling effect to the electrode as provided by air.

Several findings [12–17] explored the potential of the magnetic field in the improvement of EDM performance. The spark column in EDM, consists of charged particles mainly, electrons and ions, moving along the electrical field in a straight path. A cross magnetic field when applied to the electric field, particles change their path from a straight line to cycloidal. The radius of the cycloidal path is called as Larmor radius (R) [13]. It is represented by

$$R = \frac{mv}{qB} \tag{1}$$

where m and v are the mass and velocity of charged particles, q is electrical charge and B is magnetic flux density. Hence, the mean free path of the electron reduces from λ to λ_H [14], which is represented by

$$\lambda_H = \frac{\lambda}{\sqrt{1 + \left(\frac{e}{m}\frac{LH}{v_r P}\right)^2}} \tag{2}$$

where λ is the mean free path when there is no magnetic field and λ_H is the mean free path in presence of crossed magnetic and electric field, L is the electron mean free path in gas at a pressure of 1 torr, e is the charge of electron and v_r is electron random velocity. The reduction in the mean free path of the electron increases the ionizing collisions in plasma column. The number of ionizing collisions (α_H) in the cross electric and magnetic field [14] is presented by

$$\alpha_H = \frac{e^{-l/\lambda_H}}{\lambda_H} \tag{3}$$

where l is the distance travel by an electron without collision. Heinz et al. [15] reported the rise in plasma temperature due to cross magnetic and electric field in EDM. Bains et al. [16] reported that the magnetic field improved the MRR by 12.9% during machining of metal matrix composite in EDM. Lin et al. [12] noticed that the accumulation of debris in the gap turned into undesirable arcing and short-circuiting. It was reported that the magnetic field maintained the stable discharge condition by flushing the debris away from the narrow sparking gap. Teimouri and Baseri [17] and Bhattacharya et al. [18] noticed that the magnetic field reduced the debris deposition on the machine surface and improved the MRR and surface finish.

From the aforesaid literature review, it is established that the mixture of air/gas assistance enhances the performance of EDM. In addition, the assistance of magnetic field offered advantages to the EDM such as an increase in MRR and improvement in surface integrity. However, no attempt related to the performance evaluation of combined assistance of magnetic field and liquid-gaseous dielectric in EDM has been reported. The present paper thus aims to modify the EDM by incorporating the assistance of magnetic field and liquid-cum-gaseous dielectric together. The parametric study has been conducted to study the combined effect of magnetic field and liquid-air/gas mixed dielectric to measure the performance of the process in terms of MRR and EWR.

2. Materials and methods

2.1. Design of fixture with magnets

The fixture with magnets was designed to provide the magnetic field during the experimentation. This fixture must have the provision to change the magnetic flux density. The electromagnet is one of the alternatives to fulfill this requirement. Although, the setup becomes bulky and costly by incorporating the electromagnet. Moreover, the resistance heating in electromagnet increases the temperature of dielectric which changes its insulation property and viscosity. In order to avoid these shortcomings, the compact fixture with permanent magnets was designed. The NdFeB sintered magnets ($\varnothing 20mm \times 50\,mm$) having a surface magnetic flux density of 0.525 T were used. The magnets were mounted opposite to the workpiece as shown in Fig. 1. The screw mechanism in fixture used to translate the magnets to and fro the workpiece equally to set required magnetic flux density in the machining area. In Fig. 1(b), the center on the top surface of the workpiece is represented by point A and the distance between A and the face of the

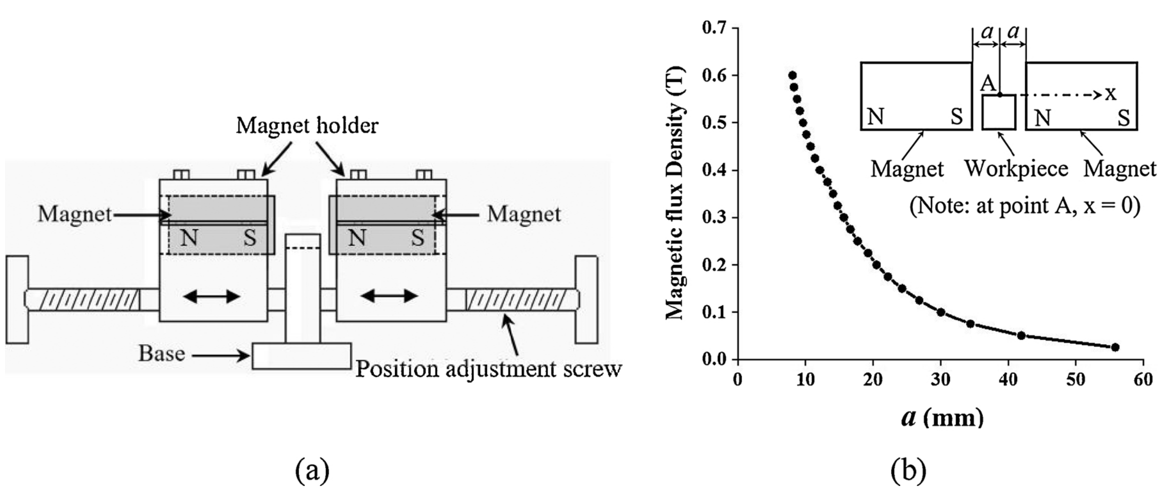

Fig. 1. (a) Schematic diagram of fixture with magnets (b) variation in magnetic flux density at point A with respect to change in the distance a.