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Research Article

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Parametric Study for Surface Quality on Magnetic Force-assisted Powder-mixed EDM

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Abstract

As per the demand of high-tech industries, advanced developed metal matrix composites (MMCs) and alloys came into the force due to their high strength-to-weight ratio but the machining of these advanced developed materials facing a tough challenge due to the hard reinforcement with a matrix material. This structural arrangement is difficult-to-cut during machining by traditional machining processes (TMPs), so people move towards non-traditional machining processes (NTMPs). Electric Discharge Machining (EDM) process is one of the popular NTMP for such materials, but it has a low machining rate and poor surface quality, so to overcome these drawbacks, researchers are working on the hybrid concept with EDM for the improvement of machining characteristics. This research article is devoted to the experimental investigation of Magnetic Force-assisted Powder-mixed EDM (MFPEDM) and its parametric study for micro-hardness, recast layer thickness, and micro-cracks density and concluded that the current, pulse-on time and powder concentration are the most significant controlling factors for machined surface integrity.

Keywords

Aluminium titanium di-boride, Conventional EDM, Micro-cracks density, MFPEDM, Recast layer thickness

Introduction

Metal matrix composites (MMCs) have great serviceable quality for aviation, shipbuilding, and high-tech structural industries. But machining challenges of such materials demand advanced/ non-traditional machining processes (NTMPs). Electric discharge machining (EDM) is the widely accepted NTMP for machining of such MMCs. Aluminum Titanium Di-boride ($Al\text{-}TiB_2$) is a newly developed MMC which have excellent values of hardness, tensile strength and Young's modulus [1] and it can be easily machined by EDM, but EDM exhibits various performance issues like poor surface quality and low machining rate, hence people moves forward to eliminating such issue by hybridizing the EDM with other physical/mechanical processes [2]. Numerous people have worked on EDM by blending the various powder particles with dielectric fluid and unfolded the improvement in machining characteristics by the observation and named the Powder mixed EDM (PEDM) [3-6]. When powder particles blended with the dielectric fluid during the machining then these particles get charged and energized ultimately created bridging effect by chain formation of powder particles between tool and workpiece gap, which increase this gap and reduce the dielectric strength resulting short circuiting takes place and done faster sparking. These particles also help in uniform distribution of spark under entire gap area which promote shallow and wider crater and improve the surface quality [3-4]. Modi and Agarwal [5] performed PEDM on Nimonic 80A by using aluminium and chromium powder as a variable parameter and concluded that chromium powder is better than aluminium for better MRR. Bhattacharya et al. [6] studied the PEDM by machining of die steel and observed the improvement in micro-hardness wear resistance of the machined surface as compared to Conventional EDM (CEDM). Some people have worked with hybridization on EDM by applying a magnetic field near the machining gap and observed the effectiveness of this Magnetic Force-assisted EDM (MFEDM) hybrid concept. When a magnetic field provides near the machining gap then the magnetic force and previously available electrical force developed a resultant force, this resultant force deflects the electron to confine and densify the plasma channel which increases the erosion efficiency as well as machining rate. The Lorentz force also helps in more ejection of debris particle from the crater and maintain the uniformity of discharge webforms during the entire machining time, thus the new concept of improvement of machining performance of non-magnetic materials [7]. Lin et al. [8] machined the SKD 61 steel on MFEDM as well as CEDM for the investigation of MRR, surface roughness, and RLT and they claimed praiseworthy improvement in all machining responses during MFEDM when compared with CEDM. Prasanna et al. [9] conducted experiments on MFEDM for machining of D2 steel to study the effect of variable controlling factors on MRR, TWR, and Ra. And they observed that all the responses increased by increasing in discharge energy. They also established the optimal settings for all machining responses using the response surface methodology approach.

Few people developed a new hybrid EDM system by combining both concepts simultaneously, which is infamous as Magnetic Force-assisted Powder-mixed EDM (MFPEDM) [10-13]. Bhatt et al. [10] examined the surface roughness and material removal rate of aluminium using MFPEDM mixed the powder with dielectric and simultaneously applied a magnetic field near the machining region during EDM and elucidated the improvement in MRR and surface finish during MFPEDM. Rouniyar and Shandilya [11] designed and fabricated the MFPEDM set-up and performed experiments on it for finding the MRR and TWR of aluminium-6061 alloy. They also studied the effect of input factors and concluded that high discharge energy and magnetic strength have increased the MRR and reduced the TWR. Sajeevan and Dubey [13] performed experiments on Al-TiB_2 MMC using MFPEDM as well as CEDM. They compared the value of MRR, Ra, and OC and reported a considerable improvement in machining responses during MFPEDM as compared to CEDM. In another study, Sajeevan et al. [14] developed an MFPEDM setup and performed the experiment to examine MRR using the Orthogonal Array L9 design approach and unfold the improvement in MRR by comparing the response of EDM and MFPEDM, they also investigated the optimal setting of input variables for MRR using artificial neural network-genetic algorithm approach.

The literature review discloses that most researchers have done their work on Hybrid EDM processes such as PEDM and MFEDM, but very little work is available on which these processes combined as MFPEDM. And most work found in which stationary magnets have been used during MFPEDM, which may reduce the effectiveness of the hybridization due to adherence of powder and debris particles on the magnet surface, so to overcome some researchers have worked by rotating two pairs of a magnet around the machining region.

In the present study, the author has performed experiments on rotational MFPEDM using the L-27 Orthogonal Array design approach on Al-TiB_2 MMC for examination of surface quality-related performances namely: Micro-hardness (MH), Recast Layer Thickness (RLT), and Micro-cracks Density (MCD). The results analyzed the effects of input variable process parameters such as current, pulse-on time, pulse-off time, and powder concentration on surface quality for MFPEDM during machining of Al-TiB_2 MMC has been done. All observations have been performed on fixed magnetic field density (0.1 tesla) and this value was taken on the basis of previous literature study.

Experimental Details

The workpiece material, tool material, powder material, and dielectric fluid were considered as Al-TiB_2 MMC, Copper, chromium (325 Mesh No.), and commercial grade SEO 450 dielectric fluid respectively for this investigation. The properties and other details of all materials were discussed in the author's previous study [13-16]. The real setup of MFPEDM system is shown figure 1.

The common controlling factors namely peak current, pulse-on time, pulse-off time, and powder concentration were considered as input parameters, and each factor was taken at three levels for experimentations. The range of each parameter was decided by pilot experimentations. All observations have been performed on fixed magnetic field density (0.1 Tesla) and this value was taken on the basis of previous literature study as discussed in previous study of the authors [13]. MH of the machined surface was measured thrice and averaging them. RLT was measured by using ImageJ software of SEM images

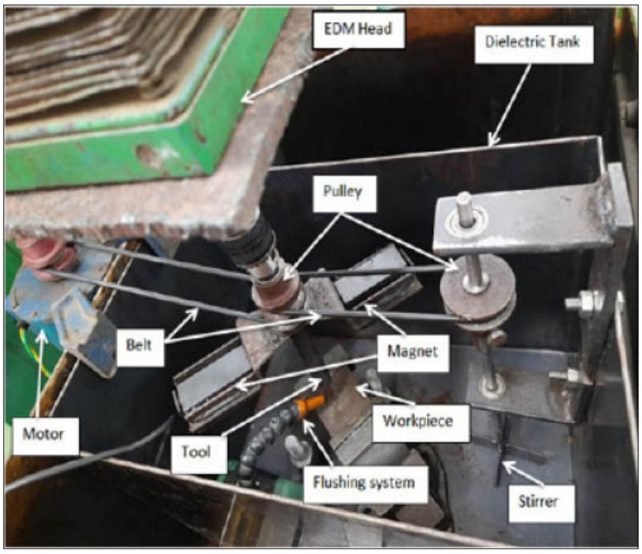

Figure 1: Actual machine set-up.

and MCD on machined surface was counted and divided by entire area at which they occurred for all observations.

The values of machining characteristics were calculated and measured for all 27 experiments and presented in figure 2.

Results and Discussion

Micro-hardness

The ANOVA plot figure 3a and 3b plot show the behaviour of input factors on the MH. Here the MH is most significantly affected by current, followed by pulse-on time and pulse-off time. MH increases by increasing in the current, and pulse-on time, the interaction plot between pulse-on time and current also depicts that the MH increased by increasing at the entire range, because the MH of the surface depends on the temperature gradient of the surface during machining, for the higher setting value of current and pulse-on time, more discharge energy/ temperature generated on the workpiece (Anode) and during the pulse-off time this temperature drop and surface hardness increases, so MH is proportional to peak current and pulse-on time.

The MH is decreased by increasing pulse-off time for initial rage because the temperature gradient decreases with increased cooling time but if this time is extended further then the chance of re-solidification of melted material on the surface increases hence MH increases at a higher value of pulse-off time. MH also increases by increasing powder concentration because of the chances of the formation of different hard compounds over the surface. Under extreme thermal stress, there may be the formation of aluminum carbide and chromium carbide on the surface which improves the MH of the machine surface, thus the MH of the machined surface increases by increasing the concentration of powder with dielectric fluid.

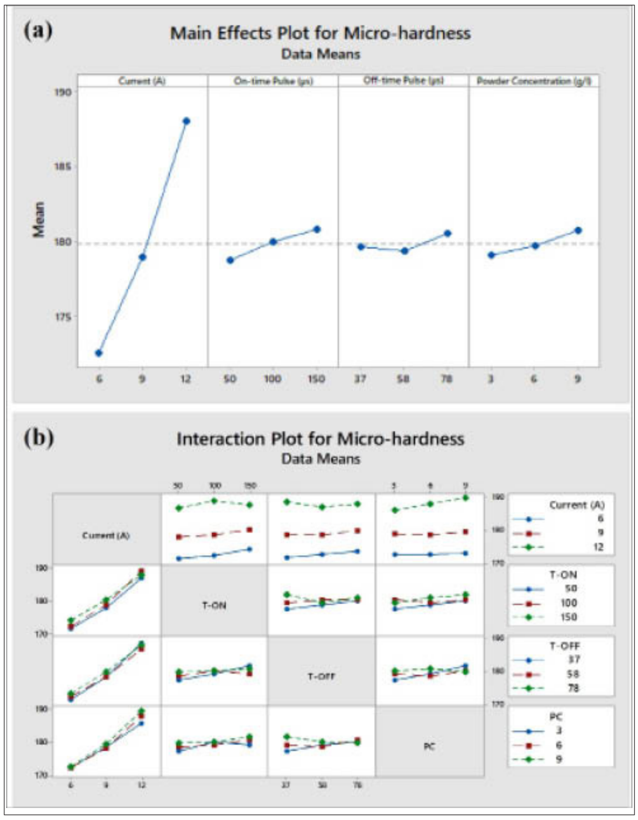

Figure 3: ANOVA plots for MH: **(a)** main effects plot and **(b)** Interaction plot.

and 5b) portrays the effect of input variables on the MCD. The current is the most significant controlling parameter for RLT. Micro-cracks are produced on the recast layer by sudden quenching or escaping residual gases, the main effect lot shows that micro-cracks are reduced first by increasing current

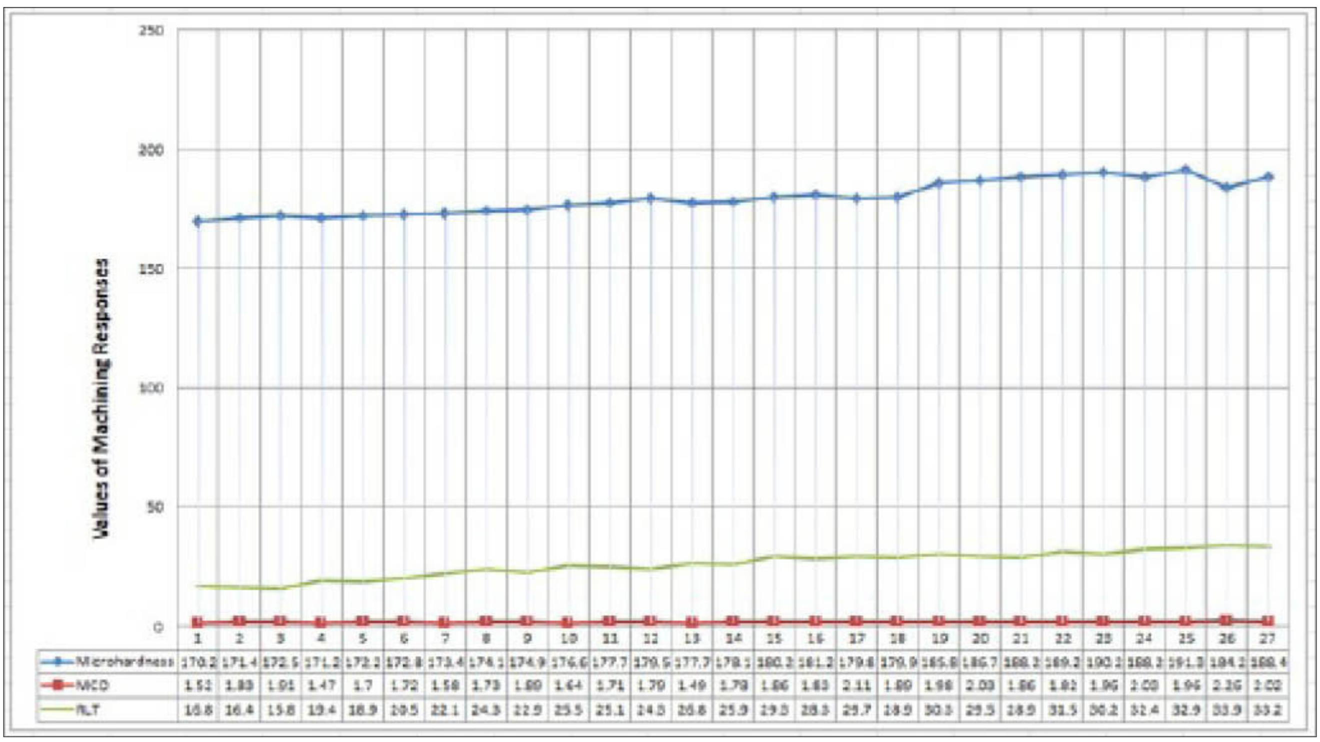

Figure 2: Experimental observations.

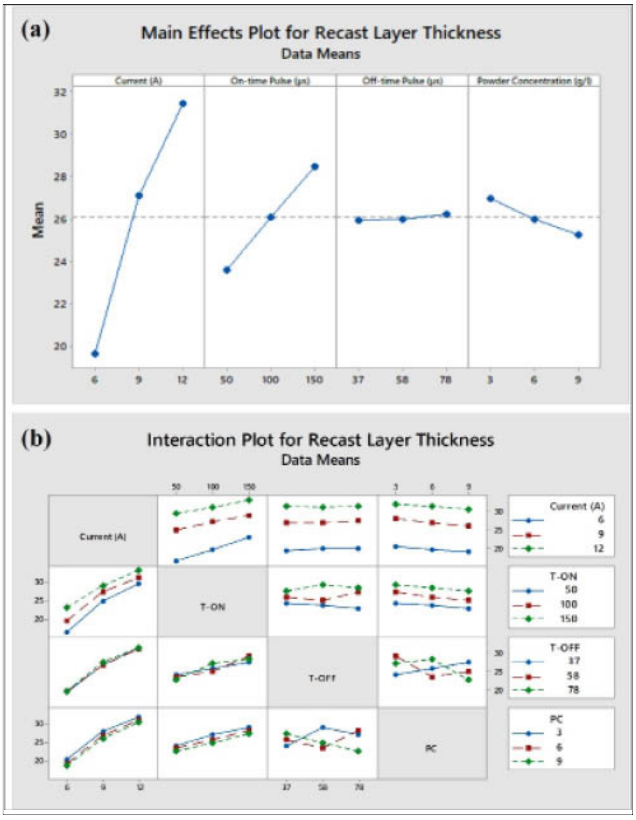

Figure 4: ANOVA plots for RLT: **(a)** main effects plot and **(b)** Interaction plot.

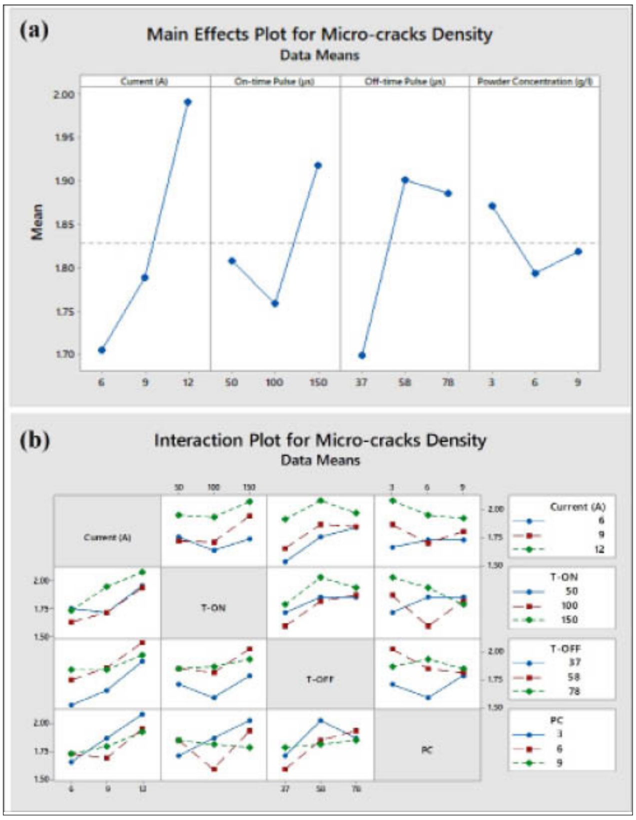

Figure 5: ANOVA plots for MCD: **(a)** main effects plot and **(b)** Interaction plot.

The process performances of MFPEDM have been analyzed during the machining of the Al-TiB_2 MMC and the following can be concluded from the present research work:

- Mixing powder in dielectric and applying the magnetic field is an effective hybridization technique during EDM to improve the process behaviour in terms of surface integrity and machining rate.
- The powder concentration gave a higher value of MH and minimum value of RLT at 9 gram per litre whenever the minimum value of MCD has been found at 9 gram per litre of powder concentration during MFPEDM of Al-TiB_2 MMC.
- The MH has decreased initially the increasing trend with the increase in and pulse-off time whereas MCD has an increasing then decreasing trend with the increase in the same input parameter.

The MH increased the trend with an increase in the powder concentration due to deposition of the hard compound of powder particles on the machined surface whereas RLT and MCD followed decreasing trend because of more expulsion of debris particles in presence of a magnetic field around the surface.

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Conflict of Interest

The authors declare no conflict of interest.

Credit Author Statement

Ram Sajeevan: Conceptualization, Investigation, Writing - original draft preparation; Avanish Kumar Dubey: Writing - review and editing, Supervision. All the authors read and approved the manuscript.

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