ABSTRACT

The growing scenario towards the miniaturization of products with more functionality and light weight has lead to the development of precision machining technologies in the area of micro-machining. Applications of micro-features on super light and high hardness alloys have made Electric Discharge Machining (EDM) as an important, reliable and cost-effective machining process. Due to its negligible machining forces and high repeatability of the process, EDM has become one of the best processes for achieving dimensionally perfect micro-features in hard-to-machine materials like Ti-6Al-4V. Though EDM is capable of machining any electrically conductive materials regardless of their hardness, challenges related to debris accumulation in the Inter Electrode Gap (IEG) and generation of secondary sparks during the EDM process are still unresolved. These machining issues affect the performance characteristics like machining rate, tool wear and surface finish. Hence this study aims to develop some assistive methods to integrate with existing EDM process to reduce the machining issues and improve the performance characteristics while machining micro-holes in Ti-6Al-4V alloys.

The selection of pulse type and its corresponding control circuit is a key to successful machining of micro-holes using EDM. This study starts with experimenting and evaluating the types of pulse circuits and selecting a circuit based on performance measures. To effectively machine micro-holes of 500µm on Ti-6Al-4V alloy, an experimental investigation was carried out using the Slope Control (SC) circuit following the Box–Behnken design. Based on the literature survey and pilot experimental trails, the most influencing machining parameters on output responses such Material Removal Rate (MRR), Tool Wear Rate (TWR) and Surface Roughness (SR) were selected. The selected machining parameters input current (I_p), pulse on time (T_{on}) and pulse off time (T_{off}) with three different levels of values for each parameter were considered for 15 experimental trails. The output responses Material Removal Rate (MRR) and

Tool Wear Rate (TWR) were analyzed using contour plots and mathematical model was developed using regression modeling. In addition, the grey relational analysis technique was applied to find the optimal parameters for achieving maximum MRR and minimum TWR. Optimal parametric values obtained were input current (I_p) 4.0 A, pulse on time (T_{on}) 2.0 µs and pulse off time (T_{off}) 6.4 µs. The achieved optimized parameters were further used to conduct experiments with assistive methods and performance characteristics of the process with and without assistive methods is compared and evaluated.

Following that, experimental investigations with Coated Electrode Assisted EDM (CEA-EDM) Process were carried out. Copper (Cu) electrodes were coated with silver, nickel, zinc to develop conductive coating and epoxy for non-conductive coating. The experimental results showed each type of electrode enhances a particular machining characteristic such as silver-coated electrode produced a higher value of MRR, epoxy-coated electrode achieved minimum TWR and zinc coated electrode showed better surface finish. A second assistive method with the use of low-frequency vibrations to the workpiece was also experimentally investigated with the help of a custom-built vibration setup of 100-500Hz frequency range and the process was designated as Low-Frequency Vibration-Assisted EDM (LFVA-EDM) of micro-holes on Ti-6Al-4V. To maintain the IEG in EDM machining, three vibratory control factors which generates amplitude less than 50µm were selected for the experimentation. The experiments conducted with low frequency vibration set-up showed a significant improvement in output responses such MRR, TWR and SR. Further, the experimental investigation with the effect of magnetic field in the sparking region was conducted and this assistive method was called Magnetic Field-Assisted EDM (MFA-EDM) of micro-holes on Ti-6Al-4V. In this MFA-EDM process, an external magnetic field set-up was developed by placing two and three Neodymium magnets of grades N35 (1.14T) and N52 (1.4T). The results showed a significant increase in MRR, TWR and SR when the magnetic field is exposed in the sparking region.

In the last phase of this research work, a combined assistive EDM machining (CELFVMFA–EDM) process was developed and experiments were conducted. In CELFVMFA – EDM process, the parameters taken for study are selected by choosing the type of coated electrode, vibratory control factor (frequency & signal current, I_s) and magnetic type which achieved maximum MRR and minimum TWR, SR in CEA-EDM, LFVA-EDM, MFA-EDM process. The CELFVMFA – EDM process shows a significant improvement in output responses MRR, TWR and SR when comparing with EDM process without the above said assistive methods. In addition, the output responses achieved with all assistive methods were compared. The result shows that all the implemented methods have contributed for significant increment in the machining efficiency of the EDM process for machining micro-holes.