Investigation on Electrochemical Discharge Micro-Machining of Silicon Carbide

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ABSTRACT

Electrochemical discharge machining (ECDM) process has great potential to machine hard, brittle and electrically non-conducting materials in micron range. The objective of this paper is to investigate into electrochemical discharge micro-machining on electrically semi-conductor type silicon carbide (SiC) material so as to study the effects of applied voltage, electrolyte concentration and inter-electrode gap on material removal rate (MRR) and radial overcut (ROC) of micro-drilled hole. Experiments were conducted based on $L_9$ array of Taguchi method with stainless steel $\mu$-tool of 300$\mu$m diameter using NaOH electrolyte. An attempt has been made to find out the single as well as multi-objective optimal parametric combinations for maximum MRR and minimum ROC. The single-objective parametric combinations were selected as 45V/20wt%/$20\text{mm}$ and $25V/20\text{wt%}/40\text{mm}$ for maximum MRR and minimum ROC respectively whereas multi-objective optimal parametric combinations was found as $25V/20\text{wt%}/40\text{mm}$. Further mathematical models have been developed between the above machining parameters and characteristics.

KEYWORDS

GRA, Micro-ECDM, MRR, ROC, Silicon Carbide, Taguchi

1. INTRODUCTION

With the rapid growth of engineering materials towards the direction from metal to non-metal and thereafter to ceramics and composites, the modern industries have developed an increasing demand for machining of advanced engineering materials irrespective of their hardness, toughness, electrical conductivity and microstructure etc. The improved properties of the materials, however, pose new challenges to the present manufacturing and process engineers, as often haunted by the requirements of machining those materials economically and efficiently. Again, the miniaturization of the products demands newer manufacturing processes and complete machining system for operating in the micron range. But, it becomes troublesome to produce 3-D micro-shapes with ceramics by the conventional machining and manufacturing techniques. Some non-conventional machining processes like LBM, USM and AWJM, etc., can be used for machining the above materials but these machining processes are very expensive. To meet the requirement of machining such important engineering materials in the micron range the machining methods

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have taken a dramatic shift from the practice of traditional machining to the non-traditional machining and finally, in turn, towards hybrid machining. Electrochemical Discharge Machining (ECDM) process has potential for micro-machining operation on non-conducting as well as harder engineering ceramic materials although it has some limitations (Tsuchiya et al., 1985; Bhattacharyya et al., 1999; Wüthrich and Fasico, 2005; Basak and Ghosh, 1997; Jain et al., 1999). Micro-ECDM is an advanced hybrid machining process that comprises the techniques of Electrochemical Machining (ECM) and Electro Discharge Machining (EDM). In micro-ECDM process, the material removal takes place due to the combined effects of electrochemical (EC) reactions and electrical spark discharge (ESD) action.

From review of past literature, it is clear that several researchers have approached different concepts to overcome the limitations of this process. Sarkar et al. (2009) performed the experimental investigation on the influence of external power circuit variables with NaOH electrolyte in order to enhance the material removal rate (MRR) during micro-ECDMing of glass. Kim et al. (2006) documented the influences of frequency and duty ratio on MRR, diametral overcut, surface roughness and tool wear rate during ECDM operation on Pyrex glass. Some researchers carried out the investigation to improve the performance characteristics of the process by using powder-mixed electrolyte, pulse voltage and combining ultrasonic vibration with ECDM (Zheng et al., 2007; Han et al., 2007, 2009). Liu et al. (2010) studied the machining performance of ECDMing of metal matrix composites so that its cutting efficiency and surface quality could be improved. Wei et al. (2011) developed a finite element based model on ECDM drilling in less than 300 μm depth referred as ‘discharge regime’ for simulating the material removal subjected to a single spark whereas Behroozfar and Razfar (2016) studied experimentally and numerically the material removal of ECDM process. But till date, as authors knowledge is concerned no investigation has been performed or reported considering inter-electrode gap i.e. the gap between tool tip and auxiliary electrode as a machining parameter during micro-machining of advanced ceramics by ECDM process. Also, most of the researchers have carried out their works only on electrically non-conducting materials (Wüthrich et al., 2005; Sarkar et al., 2006, 2008; West and Jadhav, 2007, Manna and Narang, 2012; Jui et al., 2013; Nguyen et al., 2016) and few researchers have conducted investigation on electrically conducting materials (Huang et al., 2014). But, none has conducted experiments on electrically semi-conductor type of materials. Then authors felt that it is necessary to study the effect of inter-electrode gap and other process parameters on this type of material so that manufacturing industries can create micro-shapes, features or even micro-products with these types of materials successfully. Therefore, the prime objective of the present research paper is to carry out experimental investigation on electrochemical discharge machining (ECDM) process to study the effects of various process parameters such as applied voltage, electrolyte concentration and inter-electrode gap on different machining criteria i.e. material removal rate (MRR) and radial overcut (ROC) of machined hole during micro-drilling of silicon carbide. The experimentations have been conducted based on L₉ orthogonal array of robust design. The effects of process parameters on MRR and ROC of the machined micro-hole on silicon carbide ceramics by ECDM process have been studied based on S/N ratio. But the selection of machining parametric condition for optimum results i.e. maximum MRR and proper dimensional accuracy during machining operation is a hill of task for manufacturing scientists and engineers because these are very time consuming as well as costly. To the best of authors’ knowledge, no work has been carried out till date for selection of optimum parameter setting during micro-drilling of silicon carbide. Hence, a multi-objective optimisation has been done for obtaining maximum MRR and minimum ROC using Grey Relation Analysis (GRA) technique. Further mathematical models have been developed to predict machining criteria at different parametric conditions.
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