Multi-Response Optimization of Electrochemical Machining of Al-Si/B₄C Composites Using RSM

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ABSTRACT
The present work reports the electrochemical machining (ECM) of the aluminium-silicon alloy/boron carbide (Al-Si/B₄C) composites, fabricated by stir casting process with different weight % of B₄C particles. The influence of four machining parameters including applied voltage, electrode feed rate, electrolyte concentration and percentage of reinforcement on the responses surface roughness (SR) and radial over cut (ROC) were investigated. The process parameters are optimized based on the response surface methodology (RSM) and the optimum values for minimizing surface roughness and radial over cut are voltage 15.25 V, feed rate 1.0 mm/min, electrolyte concentration 13.56g/lit and percentage of reinforcement 7.36 wt%. The quality of the machined surfaces is studied by using scanning electron microscopic (SEM) images. The surface plots are generated to study the effect of process parameters and their interaction on the surface roughness and radial over cut, for the machined Al-Si/B₄C composites.

Keywords: Al-Si/B₄C Composites, Electrochemical Machining, Percentage of Reinforcement, Radial Over Cut, Surface Plots, Surface Roughness

INTRODUCTION
Metal matrix composites (MMC) have emerged as an important class of materials, which are increasingly being utilized in recent years. Among the various types of MMC, aluminium-based composites have been found in various engineering applications such as the aerospace, defense, biomedical and automobile industries because of their inherent properties like high strength to weight ratio, low wear rate etc. Some of the typical applications are bearings, automobile pistons, cylinder liners, piston rings, connecting rods, sliding electrical contacts, turbo charger impellers, space structures, etc. (Ding et al., 2005). High hardness silicon carbide (SiC) or aluminium oxide (Al₂O₃) or boron carbide (B₄C) particles are commonly used to

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reinforce aluminium alloys, but the full application of such MMC is, however, cost sensitive because of high machining cost (Hung et al., 1995). The machinability of MMC has received considerable attention because of high tool wear associated with machining. The turning, milling, machining, or threading of MMC reinforced with Al$_2$O$_3$ particles are extremely difficult due to their extreme abrasive properties (Sahin et al., 2002). Studies on the machinability of light alloy composites reinforced with Al$_2$O$_3$/SiC fibers/particles (Tomac et al., 1992; Cronjager et al., 1992) indicate poor machinability due to the abrasive wear of tools. Moreover, the quality of the machined surface also deteriorates with tool wear (Chandrasekaran et al., 1997). Due to the above limitations several researchers have studied the machining of MMC through non-traditional machining processes.

Mathematical models of the material removal rate, tool wear rate and surface roughness were developed by response surface methodology to predict the influences of machining parameters on response factors during electric discharge machining of AA6061 wt.10% B$_4$C$_p$ (Thangadurai, 2012). The influence of process parameters like peak current, flushing pressure and pulse on time on material removal rate, surface roughness and tool wear rate in electric discharge machining of aluminium-fly ash-graphite hybrid metal matrix composites was investigated by Prasad et al. (2011).

Electrochemical Machining (ECM) appears to be a promising non-traditional machining process to produce parts from difficult to machine materials. In electrochemical machining, the metal is removed by the anodic dissolution in an electrolytic cell in which work piece is the anode and the tool is cathode. The electrolyte is pumped through the gap between the workpiece and the tool, while direct current is passed through the cell, to dissolve metal from the work piece. In ECM with flat ended universal electrode better material removal rates and low surface waviness can be achieved when compared with the ball ended electrodes (Ruszaj et al., 2001). Later on, Hocheng et al. (2005) used the concept of redistribution of electric energy to erode a hole in the thin metal of sheet. But it is very difficult to identify the optimal process parameters of ECM with this type of experimental study. Therefore, the establishment of the mathematical models is essential to correlate the input-output parameters using statistical regression analysis. Non-linear regression models for ECM were developed by Ravikumar et al., (2008) with voltage, current; flow rate of electrolyte and gap between the electrodes as input process parameters, and metal removal rate (MRR), surface roughness (SR) are treated as responses. Later on, response surface methodology (RSM) is used by Senthilkumar et al., (2009) to study the characteristics of ECM of Al/SiC$_p$ composites. They constructed the contour plots between the responses MRR and SR, and process parameters, namely applied voltage, electrolyte concentration, electrolyte flow rate and tool feed rate. A356/SiC$_p$ composites were machined by using Electro Chemical Machining process and the effect of various parameters like applied voltage, electrolyte concentration, feed rate and percentage reinforcement on the material removal rate was studied (Senthil Kumar et al., 2009). The process parameters like, electrolyte concentration, feed rate and applied voltage were optimized in electrochemical machining of EN31 steel using grey relational analysis (Gopal, 2011). Ashokan et al., (2008) used multiple regression analysis and artificial neural networks (ANN) for the multi-objective optimization of ECM process. Moreover, ANN had also been used by Abuzeid et al. (2012) for the prediction of ECM process parameters. The output of the NN contains two outputs, such as MRR and SR, whereas the input layer is provided with three inputs, namely applied voltage, feed rate and electrolyte flow rate. Fuzzy logic had also been used (Rama Rao et al., 2009a) to model the ECM process with voltage, current, electrolyte flow rate and gap between the electrodes as inputs and MRR and SR as outputs. It is also important to note that evolutionary algorithms, such as genetic algorithms (Datta et al., 2010; Jain et al., 2007; Rama Rao et al., 2009b), particle swarm optimization (Rao et al., 2008) and differential...
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