DEVELOPMENT AND EXPERIMENTAL INVESTIGATIONS INTO ELECTRIC DISCHARGE MACHINING USING RAPIDLY MANUFACTURED COMPLEX SHAPE ELECTRODE WITH COOLING CHANNEL

by

JAGTAR SINGH

DEPARTMENT OF MECHANICAL ENGINEERING

Submitted

in fulfilment of the requirements of the degree of Doctor of Philosophy

to the

INDIAN INSTITUTE OF TECHNOLOGY DELHI

OCTOBER 2020

Abstract

Rapid manufacturing techniques permit tools and die to be fabricated in a short duration of time with complex geometry. The significant contribution of the present research was to fabricate copper complex geometry electric discharge machining (EDM) electrode by using an amalgamation of 3D printing along with pressure-less loose sintering. Response surface methodology was employed to study the effect of sintering parameters (sintering temperature, heating rate and soaking time) effect on EDM electrodes essential characteristics such as density, shrinkage and electrical conductivity. ANOVA was used to investigate the significant contribution of the parameters on the responses. Density and electrical conductivity of fabricated EDM electrode was revealed to increase with respect to the rise in soaking time and sintering temperature. The interaction between the heating rate and sintering temperature for density and electrical conductivity responses signified the lesser effect of the heating rate at high temperatures. Further, multi-objective optimization was used to maximize density and electrical conductivity and to minimize volumetric shrinkage. Different shapes of EDM electrodes were fabricated at optimized parameters. In addition, the fabricated electrodes were tested on EDM of D2 steel for 5 mm depth. The dimensional analysis was carried out between the CAD model, fabricated EDM electrode and obtained cavity by EDM process. The results depicted the high efficacy of the process to fabricate complex geometry EDM electrodes.

An investigation on the machining outcome of electric discharge machining (EDM) using a rapid manufactured complex shape copper electrode was carried out. Developed rapid manufacturing technique using an amalgamation of polymer 3D printing and pressure-less sintering of loose powder as rapid tooling have been used to fabricate copper electrode from the CAD model of the desired shape. The fabricated electrode was used for the EDM of the D-2 steel workpiece. Central composite design (CCD) was employed to study the

EDM parameters (pulse duration, duty cycle and peak current) effect on the EDM characteristics such as material removal rate (MRR), electrode wear rate (EWR) and cavity dimensional deviation (DD) as overcut from electrode CAD model. ANOVA was executed to attain significant parameters along with interactions. Peak current was found to be the utmost dominating parameter for three responses. The high percentage of carbon was observed on the electrode surface after EDM at the high level of pulse duration and resulted in low EWR. The high percentage of DD was noticed at the maximum duty cycle and maximum peak current by the substantial interactions. Genetic algorithm-based multi-objective optimization was employed for the EDM parameters optimization to maximize MRR, minimize EWR, and DD. The multi-feature complex copper electrode was fabricated and used for EDM as the case study to check the efficacy of the optimized process. It was witnessed that the process was capable of fabricating complex shape cavity as per the desired CAD model shape with efficient MRR and EWR.

Moreover, a rapid manufacturing process based on the combination of polymer 3D printing and pressure-less loose sintering was explored for the fabrication of complex shape electric discharge machining (EDM) copper electrodes with the cryogenic cooling channel. The fabricated electrodes were used to EDM D-2 steel workpiece. The comparative study was performed on material removal and electrode wear rates between the solid copper electrode, rapid manufactured electrode without cryogenic cooling (RME) and with cryogenic cooling (RMECC). Also, the surface characteristics of the worn electrode and the machined workpiece were studied with and without cryogenic cooling. The significant effect of the cryogenic cooling on the electrode wear rate and the surface roughness was observed. Better surface finish, small cracks and less debris were notified on the workpiece surface machined with RMECC due to rapid dissipation of the heat from the surface of the electrode after machining. Similarly, few cracks and low carbon deposition was observed on the RMECC surface after machining as compared to RME. The sharp corner edges of the complex shape tool in RMECC was retained after machining due to low melting and vaporization of the electrode material. The dimensional deviation of the machined surface with respect to computer-aided design (CAD) model design was compared. The RMECC was found to machine the more accurate complex shape features in terms of dimensions on the workpiece as compared to RME.