ABSTRACT

Recent progress made in the field of aviation, space, automobile and others has created the need for small and micro-size holes with high aspect ratio in extremely hard and brittle materials. As the depth to diameter ratio increases, it becomes extremely difficult to produce such holes, especially, in superalloys like Inconel 718 which is a high strength, temperature resistance Ni-base superalloy. Inconel 718 is extensively used in the aerospace industry for the hot sections of gas turbine engines particularly for components such as turbine disks, blades, combustors, etc. These parts require a large number of small diameter (1-4 mm) cooling holes to maintain the working temperature to increase the operational efficiency.

Usually, Advanced Machining Processes (AMPs) are the preferred technique for drilling holes in superalloys. Among the various AMPs, Electric Discharge Drilling (EDD) process is ubiquitous for producing small diameter holes in the aerospace, automotive, tool and die, and other related industries. The advantages of EDD include: Simple tooling and its capability of drilling multiple holes simultaneously, absence of burrs, ability to drill on angled surfaces and tough superalloys.

Literature review reveals that even though hole making by electric discharge drilling in aerospace industries is a common process, not much work has been published on electric discharge deep hole drilling of Inconel 718. There is no detailed information on machining conditions such as, material removal, tool wear, surface roughness and geometrical accuracy. The most of the published EDD studies are on low carbon steels, carbides, die steels, titanium alloys, metal matrix composites and some conductive ceramics. Hence there exists a great need to study the effect of machining parameters on hole quality produced by the EDD process in Inconel 718.

In the present study, electric discharge deep hole drilling of Inconel 718 was experimented. The pertinent process parameters selected for the study were average current (I), pulse on-time (t_{on}), duty factor (\eta) and electrode speed (N). The machining performance was investigated by analysing Material Removal Rate (MRR), Tool Wear Rate (TWR), Electrode Wear Ratio (EWR) and Depth Averaged Surface Roughness (DASR). The experiments were planned according to Response Surface Method (RSM) and Central Composite Design (CCD). Three different commercial tube electrodes viz.,
copper, copper-tungsten and graphite of outside diameter around 3 mm were used for drilling. Through holes of approximately 25 mm depth were drilled using the three electrodes. Thirty one experiments were conducted with each electrode according to the CCD. Experimental data was fitted and regression analysis was done. The confirmation experiments show that predicted responses are fairly in good agreement with the experimental values and process repeatability is good. Further, high aspect ratio deep hole (l/d > 20) experiments were performed using the identified best electrode (copper) with the strongly influencing parameters.

The parametric study of EDD of Inconel 718 using copper electrode shows that: (i) MRR varies significantly with average current, duty factor and electrode speed, whereas pulse on-time has moderate effect on MRR, (ii) TWR varies significantly with average current, pulse on-time and electrode speed, (iii) EWR results shows that average current and pulse on-time have significant effect, and (iv) DASR varies significantly with average current and pulse on-time and the parameters duty factor and electrode speed have insignificant effect on DASR.

The parametric study of EDD of Inconel 718 using copper-tungsten electrode shows that: (i) MRR, TWR and EWR vary significantly with average current and electrode speed. The parameter pulse on-time is less significant, and (ii) DASR varies significantly with average current and pulse on-time. The parameter duty factor is less significant on MRR, TWR, EWR and DASR.

The parametric study of EDD of Inconel 718 using graphite electrode shows that: (i) MRR varies significantly with average current, pulse on-time and electrode speed, and (ii) TWR, EWR and DASR vary significantly with average current and pulse on-time. The parameters duty factor and electrode speed are less significant on TWR, EWR and DASR.

Copper electrode outperforms copper-tungsten and graphite electrodes with regard to MRR and surface finish. But copper has produced more electrode wear followed by copper-tungsten and graphite electrodes. Among the three electrodes tested, copper is the best choice of electrode material with respect to high MRR and good surface finish. Therefore, copper is recommended as the electrode material for producing high aspect ratio deep holes in Inconel 718 and considered for further study.
The process parameters such as average current, pulse on-time and electrode speed strongly influence the MRR, TWR and DASR for copper electrode. Hence these three parameters were selected for further study on high aspect ratio deep hole drilling (62 mm depth). The geometrical accuracy of high aspect ratio deep hole was characterized by the output responses such as hole profile, depth averaged radial overcut (DAROC), standard deviation of hole radius (STDEV) along the depth and hole quality factor (HQF). The hole profile obtained by EDD shows three distinct segments along the hole viz., wide mouth at the top, barrel shape at the midway and narrow end at the bottom of different degrees in all the holes. The DAROC is strongly influenced by pulse on-time. The minimum and maximum DAROC obtained are 1.5 and 5 % of the tool diameter. The quantitative evaluation of the hole quality was done by comparing the HQF of each hole. The parameters correspond to high HQF (1119 mm\(^{-2}\)) are \(I = 4\) A, \(t_{on} = 40\) µs, \(N = 300\) rpm and \(\eta = 60\) %. The parameters corresponding to the best HQF condition are considered as reference parameters for obtaining good quality hole profile.

The results of high aspect ratio deep hole electric discharge drilling experiments on Inconel 718 with copper electrode indicate that good quality hole with good surface finish and better material removal rate could be obtained by setting the process parameters at moderate amperage of 4 to 8 A, low pulse on-time of 20 µs and electrode speed between 200 and 300 rpm.