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Machinablity study on Electrochemical Machining – A Review

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Abstract: Electrochemical machining processes provide a viable alternative for drilling macro- and micro-holes with exceptionally smooth surface and reasonably acceptable taper in numerous industrial applications particularly in aerospace, electronic, computer and micro-mechanics industries. Electrochemical Machining (ECM) offer a better alternative or sometimes the only alternative in generating accurate 3-D complex shaped macro, micro and nano features and components of difficult–to-machine materials. Technological advances reported in electrochemical machining processes, which reflect the state of the art in academic and industrial research and applications, are briefly reviewed in this paper.

Electrochemical Machining :

Significant advances during the 1950s and 1960s emerged ECM as an efficient technology, in the aerospace and aircraft industries. Electrochemical machining is also another advanced machining technology which offers a better alternative or sometimes the only alternative in achieving precise 3-D complex-shaped features and components of difficult-to-machine materials. The advantages of ECM over other traditional machining processes include its applicability, disregarding the material hardness, comparable high material removal rate, no tool wear, and achievement of fine surface features and the production of components of complex geometry with crack-free and stress-free surfaces. Therefore, ECM has been utilized in many industrial applications, including engine casings, turbine blades, gears, bearing cages, molds and dies as well as surgical implants.

ECM is often termed as 'reverse electroplating', in which it removes material in place of adding it. This is totally based on Faraday's law of electrolysis. A computer simulation of cut-and-try procedure for designing tool shape in the ECM of prescribed work geometry and showed that an optimum value of the feed-back factor for iterative modification of the tool shape exists[1]. Micro-ECM used to fabricate various 3D micro-structures such as micro-holes and micro-grooves. The final shape of the work-piece is nearly negative mirror image of the tool electrode[2]. Micro- drilling is an essential process in the electronics, aviation, and semiconductor industries. Since micro-drills have low rigidness and a high aspect-ratio, precise drilling parameters are required to prevent tool breakage from excessive thrust force or torque. An attempt made to machine the alumina ceramic to investigate the effects of drilling parameters on hole characteristics[3]. Electrochemical machining (ECM) has become one of the most potential and useful non-traditional machining processes because of its capability of machining complex and intricate shapes in high-strength and heat-resistant materials. For effective utilization of the ECM process, it is often required to set its different machining parameters at their optimal levels[4]. Influences of working parameters of EMM, such as pulsed duration, applied voltage, pulse frequency, electrolyte concentration, tool feed rates, and hole depth, on the hole overcut[5]. The effects of process parameters such as voltage, electrolyte concentration, pulse duty cycle, and feed rate on the machined hole diameter[6]. Given the same voltage, with an increasing cathode feed rate, the MRR was shown to increase while the surface roughness value and the side gap decreased. Under the same cathode feed rate, the MRR decreases, while the side gap and the surface roughness increase as the electrochemical machining application voltage increases[7].

Overview on Tool Electrode Design:

The principal issues in ECM development, tool design, pulse current, micro-shaping, finishing, numerically-controlled, environmental concerns, hybrid processes, and recent industrial applications[8]. EMM was reported to possess the ability of being effectively used for high precision machining operations, that is, for accuracies of the order of ±1 μm on 50 μm. Further research into EMM was noted to potentially open up many challenging opportunities of improvement towards greater machining accuracy, new materials machining and generation of complex shapes for effective utilization of ECM in the micro-machining domain [9]. Wedge-shaped electrodes for drilling inclined holes. Theoretical and experimental analyses showed that inclined hole machining using wedged electrode distributed the electrolyte flow more uniformly and showed the way to a more stable machining process. Hence, wedged electrode could be used in ECM drilling to efficiently drill high-quality holes with large-inclination angles. A difficult problem fabricating deep- and micro-holes on the difficult-to-cut metals in the field of aviation manufacturing. The experimental research of electrochemical drilling technology with high-speed micro-electrode for fabricating deep micro-holes was carried out. The influences of rotary speed on machining precision and stability were studied. The holes, which the diameter was about 400 μm, the aspect-ratio was more than 10, and had steep wall and sharp edges were fabricated successfully on the nickel-base super alloys on self-developed high-precision micro-electrochemical machining system. It was proved that the high-speed electrochemical drilling process for fabricating deep- and micro-holes had a huge potential and broad application prospects[10].

Overview on Machining Performance

The basic characteristics of each group of methods were discussed based on different machining phenomena[11]. Capable methods were introduced in detail hinting at suitable areas of application. Finally, the state of these technologies was shown with examples of experimental and practical applications. The EMM micro-hole making process was noted to satisfy the quality requirements with respect to their geometrical characteristics like over-cut, taper, aspect-ratio or metallurgical characteristics like heat affected zone and micro-cracking[12]. An experiment with a developed setup by varying the machining voltage, electrolyte concentration, pulse-on time, and frequency on copper plate. In the study, they reported that a considerable amount of MRR at a moderate accuracy could be achieved with a machining voltage of 6–10 V, pulse-on time of 10–15 ms, and electrolyte concentration of 15–20 g/l were conducted[13]. The influence of various predominant factors of EMM and reported the industrial application of EMM such as surface finishing of print bands, nozzle plate for ink-jet printer head and production of high accuracy holes. The highest possible amount of material removal and accuracy was achieved at 3 V machining voltage, 55 Hz frequency and 20 g/l electrolyte concentration when machining copper plates[14]**.** The world-wide technical developments and state-of-the–art of electro-physical and chemical micromachining processes has been reported. Issues related to the supporting technologies such as standardization, metrology and equipment design were briefly discussed. Additionally, non-technological issues, including environmental effects and education were also discussed[15]. The latest technologies in micromachining. Based on the study, they concluded that challenges still existed in fields like innovation, in workpiece and tool material, development of auxiliary tooling equipment together with process combinations have been discussed [16]. The effect of micro-sparking and stray-current effect on the machining accuracy and surface quality through the response surface methodology approach. Based on the studying the optimal machining parametric combination for the lowest value of micro-spark and stray-current affected zone were pulse on/off ratio of 2.1618, machining voltage of 2.8347 V, electrolyte concentration of 10 g/l, voltage frequency of 35 HZ and tool vibration as 100 Hz were experimentally investigated[17]. Noted that the EMM was still in its initial stages of development and a lot of research needed to be done to improve MRR, surface quality and accuracy by optimizing the various process parameters[18]. The use of micro-ECM to fabricate various 3D microstructures such as micro-holes and microgrooves. By controlling pulse conditions and utilizing a modified tool electrode, micro-features were machined on the side wall of a micro-hole. Based on experiments, they concluded that longer pulse on–time increased the side gap have investigated[19]. The influence and behavior of electrolyte concentrations, pulse amplitude, pulse frequency, duty-ratio and micro-tool feed rate on material removal rate and the accuracy of the micro-channel. It was found from the study that for micro-profile generation, the micro-tool feed rate and electrolyte concentration were the most influencing parameters are studied[20]. Theoretical and experimentally studied the applications of the pulsed EMM using ultra nanosecond and short microsecond pulses on machining accuracy and surface quality. The study revealed that both types of pulses proved their legitimacy for micromachining with high accuracy[21]. Conducted an experimental study on the influence of shape of tool electrode tip on machining rate and overcut for 304 stainless steel. The tool electrode tips of different shapes like flat, conical with rounded and truncated cone were used for this study[22]. Being a complex process, it is very difficult to determine optimal parameters for improving cutting performance was noted[23]. The effects of process parameters such as voltage, electrolyte concentration, pulse duty cycle and feed rate on the machined hole diameter have studied [24,25].

Given the same voltage, with an increasing cathode feed rate, the MRR increased while the surface roughness value and the side-gap decreased. Under the same cathode feed rate, the MRR decreased, while the side-gap and the surface roughness increased as the electrochemical machining application voltage increased was observed[26]. The material removal rate, machining time, and the size of fabricated micro-hole were significantly influenced by the micro-tool dimension was found[27].

Overview of Process Optimization

The application of the Taguchi method with fuzzy logic for optimizing the EDM process with multiple performance characteristics. Based on the experiments the performance characteristics such as electrode wear rate and MRR are improved through this approach. Hence the optimization methodology developed in this study is useful in improving multiple performance characteristics in the EDM operations was reported[28]. The EMM parameters such as gap voltage, gap current, pulse on-time, pulse off-time and electrolyte concentration on the MRR and overcut. They have used L_{18} Orthogonal array to determine the S/N ratio and ANOVA. Based on the experiments they concluded that pulse on-time and electrolyte concentration is the most significant parameters for MRR. Gap current and electrolyte concentration are the influencing parameters for lesser overcut were experimentally investigated[29].

An applied fuzzy logic analysis together with Taguchi Technique to optimize the precision and accuracy of high-speed electrical discharge machining (EDM) process. The most important factors affecting the precision and accuracy of the high-speed EDM process have been identified as pulse time, duty cycle and peak value of discharge current, which account for about 81.5% of the process variance[30]. An attempt made to machine the A356/SiC_p composite work-material using electrochemical machining process. The author reported that Taguchi's L_{27} orthogonal array was chosen to design the experiments and 54 trials were conducted to study the effect of various parameters like applied voltage, electrolyte concentration, feed rate and percentage reinforcement on maximizing the material removal rate[31].

Conclusion

1. It is evident from the literature survey that only a few researchers have studied the performance of EMM on AMCs. Further studies are required to commercialize the technology.
2. The machining rate as well as overcut increases with the increase in machining voltage and electrolyte concentration.
3. Voltage and electrolyte concentration were the most significant factor that influences the MRR and overcut.
4. Taguchi methodology and grey-relational analysis were used in most of study for EMM process. It does not involve complicated mathematical theory or computation and thus can be employed by the engineers without a strong statistical background.
5. Further experimental studies, especially micro structural analysis can be carried out in order to understand the material structural change in the machined zone.
6. More research is recommended to accurately monitor the purity, temperature and velocity of electrolyte at IEG.

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