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Research Paper

VALUE ENGINEERING OF MICRO-MANUFACTURING USING ECM AND ITS APPLICATIONS

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In the experiment, typical results at the microscopic level, such as fine grating and micro indenting are demonstrated. It is suggested that a strategy of combining aspect in a centralized and distributed manner might be use to increase both productivity and flexibility in manufacturing. The current techniques for micro manufacturing mostly are silicon based. These manufacturing techniques are not suitable for use in demanding applications like aerospace, micro factory and bio-medical industries. Micro-electrochemical machining removes materials while holding micron tolerance and μECM can machine hard a navel μECM utilizing high frequency voltage pulses and closed loop control. The work piece materials were used as "Coinage metals". The research studied the effect of various parameters. The experimental data on small drilled holes agreed with theoretical modal burns can be effectively removed by optimal μECM. A sacrificial layer helped to improve the hole profile since. It reduced above 50% corner rounding. It electrochemical manufacturing localization is closely related with accuracy and the accuracy will be improved when the localization is enhanced. Micro holes were electrochemical drilled in stainless steel using nanosecond pulse power, millisecond pulse power and direct current power. The experimental results showed that the localization could be significantly enhanced using nanosecond pulse power.

Keywords: Localization, Coinage metals, Accuracy, Electrochemical, Micromachining

INTRODUCTION

Engineering on the micro-scale has become increasingly attractive and important due to the further requirements for finer, smaller and more precision. However, the fabrication of small parts of dimensions in micrometer is still a challenge for modem manufacturing system, especially metal micromachining. Traditional cutting machining is hardly competent for micromachining due to the difficulty of tool

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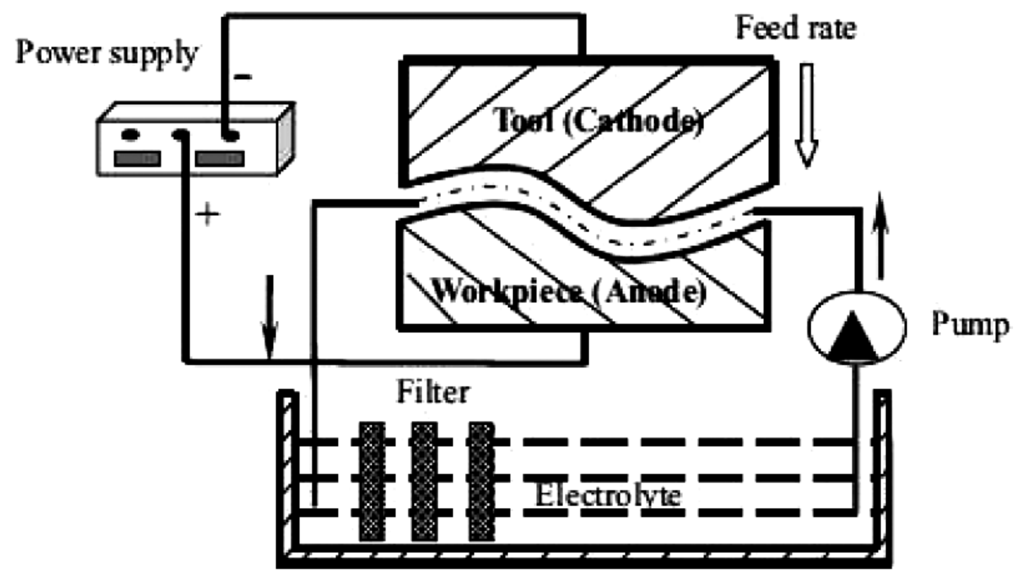
fabrication, cutting heat generation and tool wear. In nontraditional machining processes, micro electric discharge machining, laser beam machining and focused ion beam and so on are superior micromachining methods, but they have their respective limitations. Electrochemical machining is an anodic dissolution process of metal work piece ion by ion (Figure 1). ECM process has been used widely as a practical machining method of metal because of its various advantages such as no tool wear, absence of stress, high MRR. Due to the tiny size of ions, ECM possesses the tremendous potential for micromachining at micro to meso scale. However, ECM still lags far behind other processes such as electric discharge machining in the micro-machining field because of the difficulty in controlling machined shape and larger machining gap during ECM. In this paper, the aim of the research work is to develop a set of experimental equipment and explore the process of micro-ECM.

PRINCIPLE OF ELECTROCHEMICAL MICROMACHINING

Under low machining current density, the good machining accuracy can be achieved as a result of the passivation of $NaNO_3$ solution. Since the micro tool electrode is very thin, stationary electrolyte is employed to guarantee better machining accuracy. When lower concentration of electrolyte and lower machining voltage are employed, the machining gap is very narrow, so it is very difficult for fresh electrolyte to flow into the machining gap, and product of electrolysis and electrolytic heat can not be removed easily. However, the rotation of tool electrode at very high speed can greatly improve the hydrodynamic conditions, and thus ensure the abundant supply of fresh electrolyte and the successful removal of electrolytic product. Under lower machining voltage and lower concentration of electrolyte, the machining

Figure 1: Electrochemical Machining

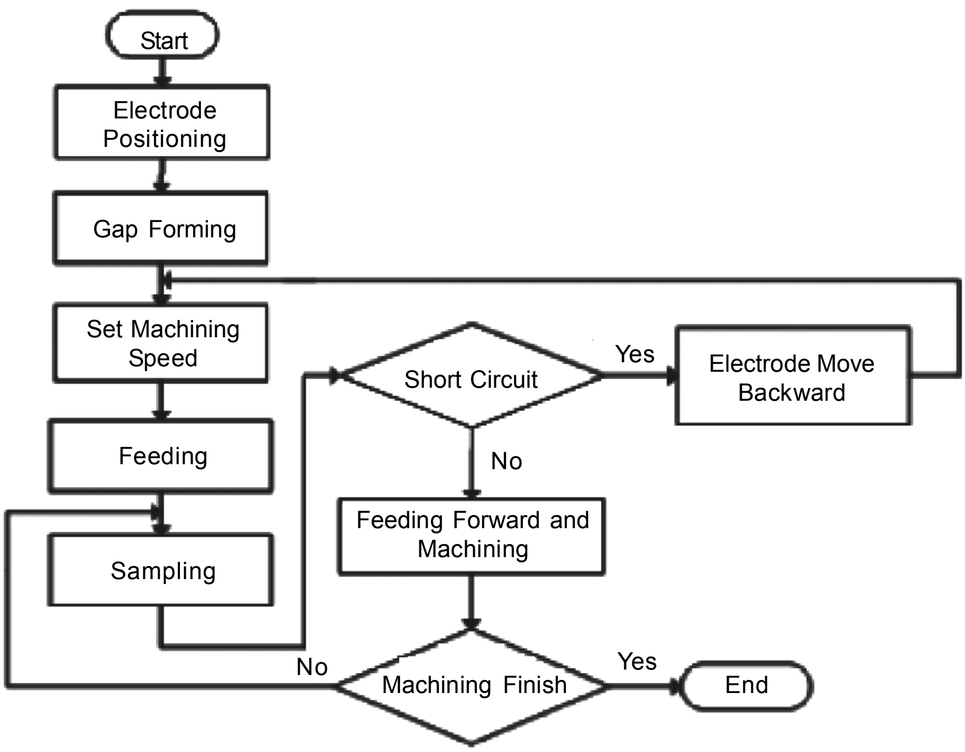


current is very low, thus the passive layer is formed on the work piece surface as a result of the passivation of sodium nitrate ($NaNO_3$) solution. This passive layer prevents the work from future dissolution. However, the rotation of tool electrode can make electrolyte in the narrow machining gap flow rapidly in close proximity to the tool electrode. The rapid flow of electrode thought the narrow machining gap in virtue of the rotation of tool electrode can not only improve the removal of electrolytic product and the supply of fresh electrolyte but also prevent formation of passive layer in very narrow machining gap. When the electrode gap is kept at a very small value, the micro tool electrode can give a high current density, so the machined surface of work piece in the tiny machining gap is kept activated and stands in the transpassive region in the whole machining process, and the micro-ECM can successfully. The metal of non-machined surface far from the tool electrode can not be removed due to the protection of passive layer, the machined metal by micro-ECM is only confined to a very small region in close proximity to the tool electrode, and the dissolution of anodic metal can be localized. Hence the better resolution of machined shape can be obtained.

MACHINING GAP CONTROL

The gap control between micro tool electrode and work piece is one of most important factors influencing machining accuracy, so the reasonable narrow gap must be maintained in the process of micro-ECM. Figure 2 shows the flow chart of gap control strategy in this work.

Figure 2: Flow Chart of Gap Control



The positions of the micro tool electrode and the clamped Work piece are determined through contact sensing function of the multifunctional machine tool, and then tool electrode is withdrawn about 10pm to form sound machining gap. Proper machining speed must be set in advance through the system specially designed for micro-ECM according to the experience before machining. Then micro tool electrode is fed to start machining and uniform machining speed is adopted during micro-ECM. The short circuit detection system detects periodically whether or not short circuit occurs through Hall current sensor during micro-ECM. When tool electrode touches work piece surface or the distance between tool electrode and work piece is only several microns, the machining current jump up instantly and the voltage of the sampling resistance soar. Thus the short circuit can be detected by the short circuit detection module. When short circuit occurs, the pulsed power supply is switched off immediately and the tool electrode is drawn back several micrometers rapidly to avoid short circuit damage. Computer automatically regulates the feed rate and afterwards switches on the pulse supply. Then the micro tool electrode is fed to continue machining. By this machining gap control strategy, the machining gap can be controlled within about 10 ptm.

RESEARCH METHODOLOGY

Section A

Electrochemical machining is a material removal process similar to electro polishing. In this process the work piece to be machined is made the anode and the tool is made the cathode of an electrolytic cell with a salt solution being used as an electrolyte. The tool is normally made of copper, brass, or stainless steel. The tool and the work piece are located so there is a gap between 0.1 mm to 0.6 mm between them the tool is designed so that it is the exact inverse of the feature to be machined. On application of a potential difference between the electrodes and subsequently when adequate electrical energy is available between the tool and the work piece, positive metal ions leave the work piece. Since electrons are removed from the work piece, oxidation reaction occurs at the anode which can be represented as,

$$M \rightarrow Mn^{+} + ne^{-} \qquad \text{...(1)}$$

Where n is the valence of the work piece metal. The electrolyte accepts these electrons resulting in a reduction reaction which can be represented as,

$$nH_2O + ne^{-} \rightarrow n/2\ H_2 + nOH^{-} \qquad \text{...(2)}$$

Hence the positive ions from the metal react with the negative ions in the electrolyte forming hydroxides and thus the metal is dissolute forming a precipitate. The electrolyte is constantly flushed in the gap between the tool and the work piece to remove the unwanted machining products which otherwise would grow to create a short circuit between the electrodes. The electrolyte also carries away heat and hydrogen bubbles. The tool is advanced into the work piece to aid in material removal.

Electrochemical machining can be used to machine either a single hole or a series of holes with the same characteristics. The tool is designed so that there is electrolyte flow both around and along the length of the electrode or through a hole inside the electrode so that the precipitates flow out. Flushing the precipitates is crucial in hole drilling because otherwise the removed material would pile up and form a short circuit. Most of the material is removed in the gap between the bottom of the tool and the work piece; however the high current densities at the tip of the cathode removes some material at the sides of the cathode as the tool progresses into the work piece. This enlarges the hole because further material leaves as the tool progresses into the work piece. This can be overcome by coating the tool sides with an insulating material so that machining occurs only at the tool base or tip. Since the hole shape depends on the stationary cathode's shape, the holes drilled need not be round The position of the tool and the flow path of the electrolyte in a hole drilling operation are shown in Figure 3. Since material is removed radially in ECM, the tool must compensate for this removal. Figure 4 shows the expected cavity shape to be formed with the given tool and the shape finally obtained.

Figure 3: Hole Drilling Using ECM

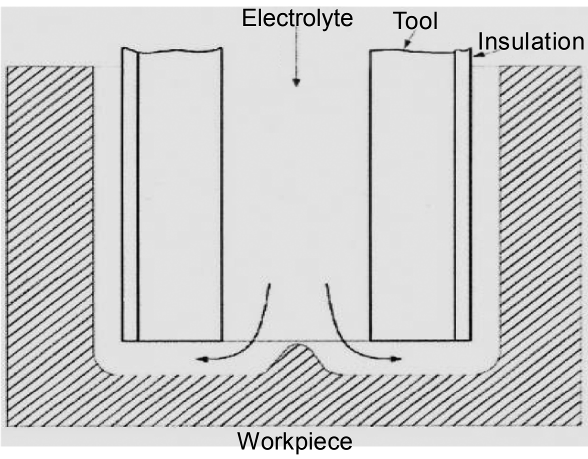
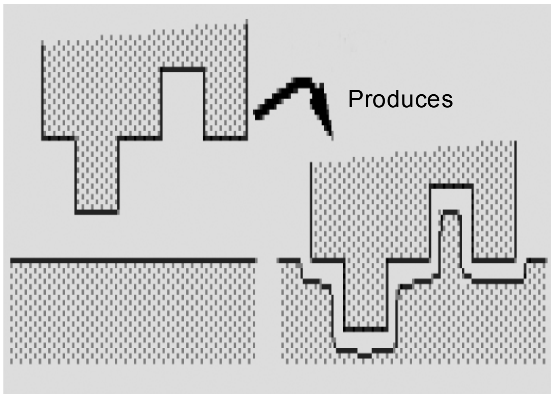


Figure 4: Shape of Tool and Cavity Formed After Machining



The amount of material removed is determined by Faraday's first law which states that the mass of the substance removed at an electrode is proportional to the quantity of current passed to that electrode. So,

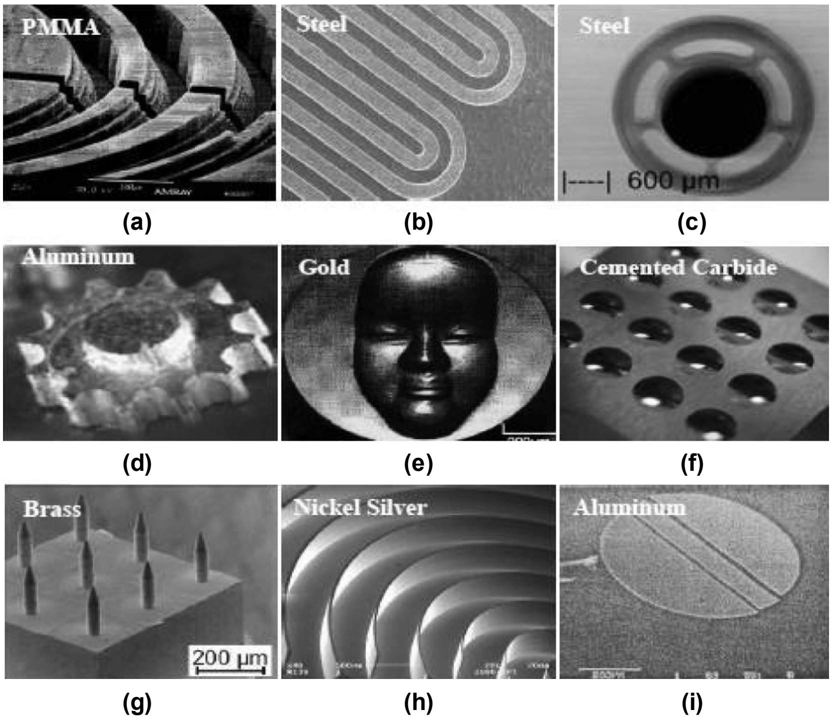
$$V = Cit \quad ...(3)$$

Where = volume of metal removed (mm^3), C = electrochemical constant (mm^3/amp-s), I = current (amps), t = time (sec).

Current and Voltage

Current density depended on the rate at which ions arrived at respective electrodes which was proportional to the applied voltage, concentration of electrolyte, gap between the electrodes, and tool feed rates. As the tool approached the work, the length of the conductive current path decreased and magnitude of current increased. This lessening of the gap and increase in current continued until the current was just sufficient to remove the metal at a rate corresponding to the rate of tool advance. The total amperage required for machining of the work piece could be calculated by multiplying the current density and the surface area being machined. When the equilibrium gap approaches zero value, over voltage

Figure 5: Examples of High Accuracy of Micro Milled, Micro Holes and Micro Structure

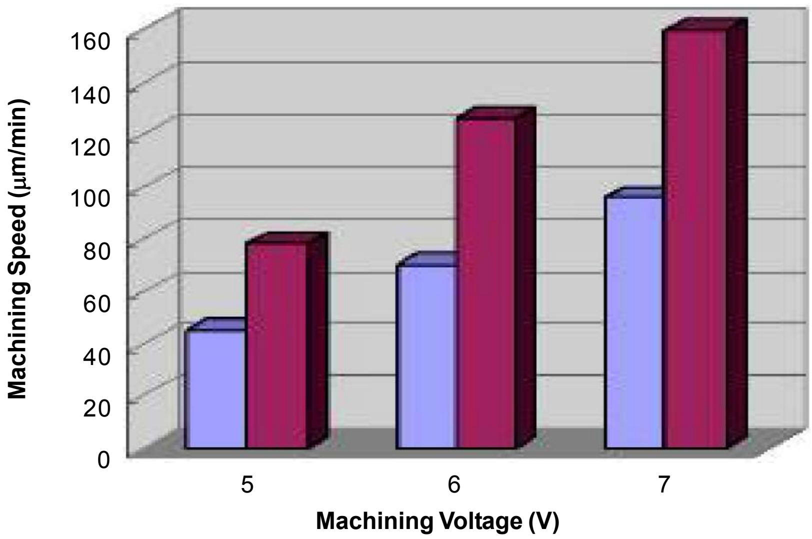


approached applied voltage (Figure 6). Over voltage (ΔV) was calculated by Equation at various equilibrium gap for a given valency,

$$\Delta V = V - \rho ZF/KA\ Y_e f \quad ...(4)$$

where V is the Voltage, K is the conductivity, ρ is the density, Y_e is the equilibrium gap, Z is the valency, f is the feed rate, and A is the atomic weight. Over voltage was a parameter which

Figure 6: Plot of Current Density versus Over Voltage



restricted material removal rate and was sensitive to tool feed rate and equilibrium machining gap. The plot of over voltage versus current density during machining an aluminum sheet using brass cathode with 1.5 M sodium chloride electrolyte is given in Figures 7 and 8, The parameters for the plot Where $A = 26.97$, $Z = 3$, $V = 40$ V, $F = 96500$, $K = 0.184$ Ohm-1 cm^{-1}, $T = 20$ °C, and $f = 0.000667$ cm/s.

Figure 7: Variation of Micro-Hole Diameter with Pulse Frequency

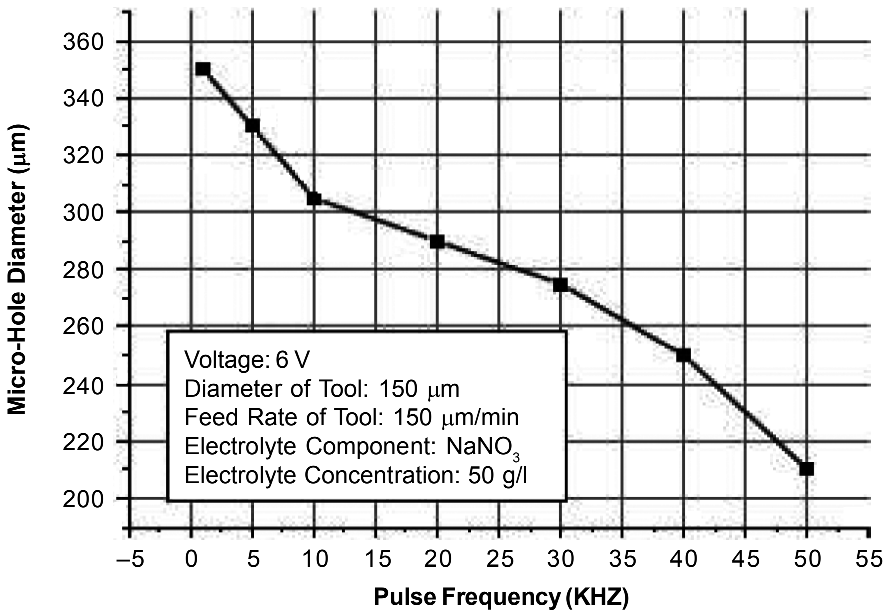
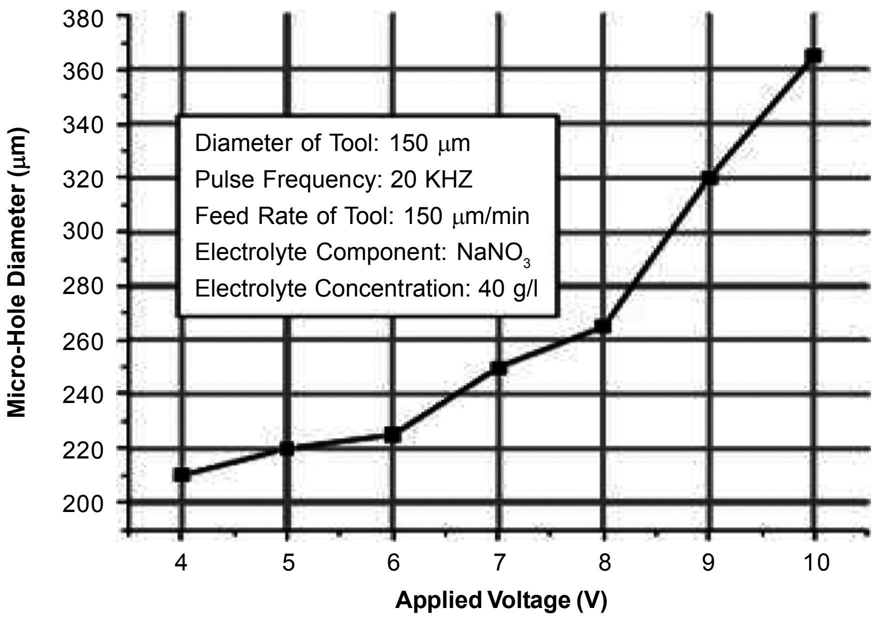


Figure 8: Variation of Micro-Hole Diameter with Applied Voltage



Section B

Electrochemical micro-machining was carried out in the electrolyte of 0.2 M1 $NaNO_3$ to facilitate dissolution of metals because the removed materials were carried away in the way of metals ions. The voltages applied in the cathode and the anode was kept to be 5 V. The work piece's materials were a nickel foil with 100 μm thickness.Φ25 μm tungsten shaft prepared by the deep immersion method was employed as the cathode tool. To reduce the diameter of the electrochemical micro machined hole. The inter electrode gap needs to the in the order of 5 to 20 μm. In our experiment, the distance between the cathode tool and the anode was 5 μm (Figure 9).

Figure 9: Diagrammatic Sketch of Edges-Cuts Electrode and Deep Micro Drilled by Micro-ECM

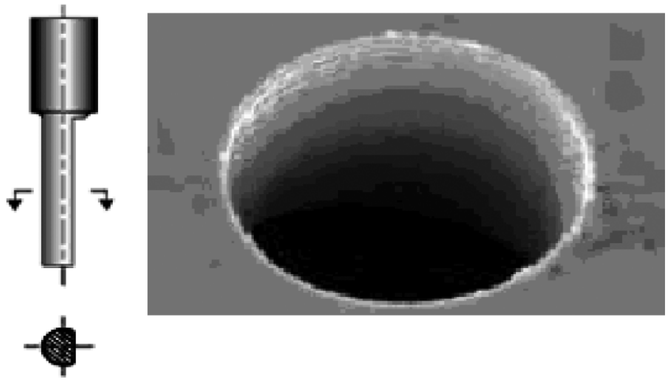


Figure 10: (a) Feed Rate of Tool: 20 μm/min (b) Feed Rate of Tool: 50 μm/min Micro-Holes Machined with Different Tool Feed Rate

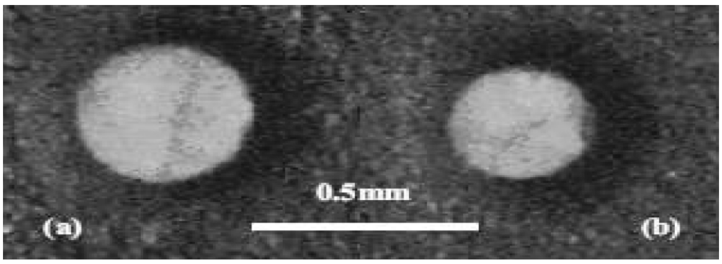
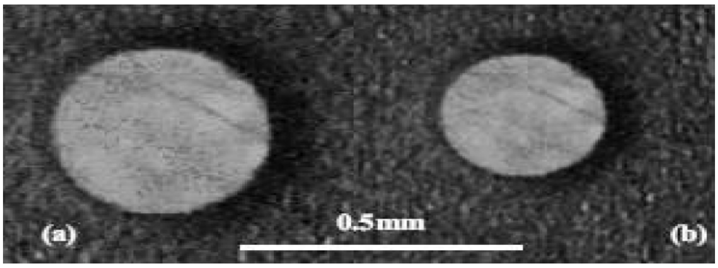


Figure 11: (a) Pulse Frequency: 10 KHZ; (b) Pulse Frequency: 50 KHZ Micro-Holes Machined with Different Pulse Frequency



THE PRESENT AND FUTURE STATUS OF ELECTROCHEMICAL MICRO MACHINING

High-rate anodic electrochemical dissolution is a practical method of smoothing and shaping hard metals by employment of simple aqueous electrolyte solutions without wear of the cathodic tool. ECM can offer substantial advantages in a wide range of cavity-sinking and shaped-hole production operations. Control of the ECM process is improving all the time, with more sophisticated servo-systems, and better insulating coatings. However there is still a need for basic information on electrode phenomena at both high current densities and electrolyte flow-rates. Tool design continues to be of paramount importance in any ECM operation. The use of computer-aided design to predict cathode tool profiles will continue to advance. Recently developments in ECM practice have dwelt on the replacement of constant DC by pulsed currents (PECM). Significant improvements in surface quality have been claimed. Much smaller electrode gaps may be obtained, for example, below 0.1 mm leading to improved control of accuracy, for example to 0.02 to 0.10 mm, with dies, turbine blades, and precision electronic components. The key to further advancement in PECM lies in development of a low cost power supply. Successful development of technique will enable on-line monitoring of the gap size, enabling closer process control.

The model for material removal rate can include the effect of pulse OFF duration and flow rate to accurately predict the material removal rate.

The advent of new technology for controlling the ECM process and the development of new and improved metal alloys, which are difficult to machine by conventional means, will assure the future of electrochemical micro machining.

CONCLUSION

A novel μECM system was developed:

- Using high frequency pulses.
- A model was developed for material removal rate using pulsed current.
- The system was used to successfully form micro holes and for profile refinement.
- Experimental data on small drilled holes agreed with theoretical data within 10%.
- Micro burrs can be effectively removed by optimal μECM setup.

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