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MICRO-ELECTRODE ARRAY AND MICRO-HOLE ARRAY FABRICATION BY COMBINED MICRO-WEDM AND EMM

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A technology of microelectrode array and micro-hole array fabricated by combined micro-WEDM and EMM(Electrochemical micromachining) was successfully developed. Process of Micro-WEDM(wire electrical discharge grinding) technology for microelectrode array fabrication is assessed. 10×10 micro-electrode arrays are got, the width of squared section for each electrode is about 30μm, the high is about 600μm and the distance between neighborhood electrodes is about 70μm, and 10×10 square micro-hole arrays fabricated by these microelectrode arrays are got by micro-EDM, the diameter of each hole is about 50μm and the width is about 80μm. Working efficiency of using microelectrode array and single electrode to machine micro-hole array by Micro-EDM is compared, the former has higher efficiency. Then 10×10 micro-hole arrays are fabricated by 10×10 square micro-electrode array of 40μm high by EMM, the diameter of single hole is about 100μm and deep is 30μm. Affected by duplication error and repeated error of EMM, the micro-hole array show obvious circular. New technology of large scale microelectrode array and micro-hole array fabricated by combined micro-WEDM and EMM is proved to be feasible and high efficient.

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Keywords: Microelectrode array; Micro-hole array; Micro-WEDM; EMM

1. Introduction

In recent years, with the development of modern science toward miniaturization, the role of micromachining technology is also increasingly important. Non-traditional machining (NTM) is the foreland of machine manufacture for its property of processing without macro-forces, so it develop rapidly and application more and more widely, especially in hard machining materials, complex shape, and thin wall parts[1,2]. High-density micro-hole fabrication by using a single tool electrode has limits in throughput and precision because of positioning error and tool wear. Thus microelectrode array fabrication is fundamental of high-density micro-hole machining. LIGA-fabricated microelectrode array is reported in Japan, 20×20 Cu microelectrode array is made by LIGA, with 20μm diameter and 300μm length [3], the micro-hole array fabricated by the microelectrode array had size difference between 30–32μm in diameter. Zeng Weiliang et al presented reverse copying technology for microelectrode array fabrication by ultrasonic enhanced micro-EDM[4]. An array of 5×5 AgW electrodes with 30 μm in diameter were obtained, height-to-width aspect ratio is more than 8. T.Masuzawa et al proposed a method of Large-Scale Production of micro holes by micro-EDM[5]. By using twin WEDG (wire electrical discharge grinding) equipments, multiplex pulsed power generators, and a set of automatic electrode feed supply, the developed system realized both fabrication of microelectrode and machining of micro holes synchronously. Reference[6] reported state of the art for micro manufacturing technology of Matsushita Electric Industrial Co.

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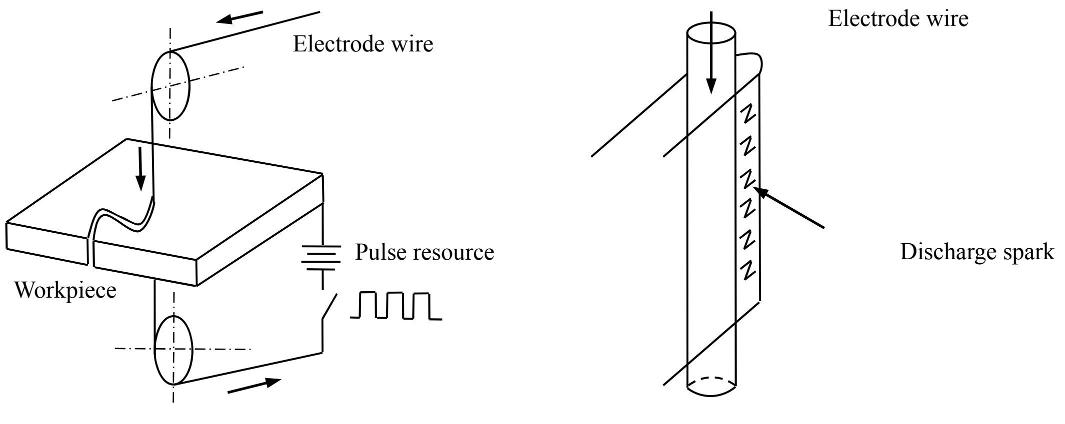
Electrochemical micromachining (EMM), as one of the micro machining, has been paid more attentions extensively by many scholars because of the characteristics of untouched machining, the great proportion between depth and width, and micro 3D structure realized easily. With the developments of EMM, the fabrication of micro hole and micro 3D structure which are made by micro cylindrical electrode is one of the main techniques of EMM machining currently [7,8].It is convenient and high efficient to fabricate micro-holes in batch with micro-electrode array by EMM, so machining precision of EMM is much important for micro-holes fabrication[9]. There are many influence factors of machining precision such as parameters of the machining gap, voltage drop, electrolyte conductivity, feeding rate, current efficiency and so on[10].

This study described and assessed a new technology of microelectrode array and micro-hole array fabricated by combined WEDM and EMM, the technology has advantages of high efficiency and low cost.

2. Process of Micro-WEDM Technology for Microelectrode Array Fabrication

Micro-WEDM is a kind of micro-EDM, which uses a pulsed spark discharge between the workpiece and micro wire electrode, resulting in an instant high-temperature partial melting and vaporization of the workpiece material, so as to achieve the purpose of ablation processing.

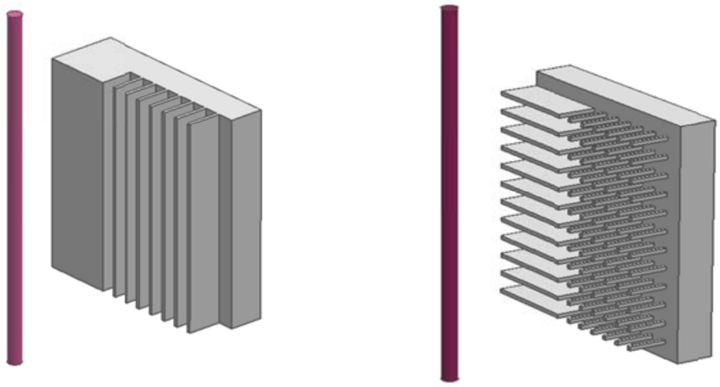
The micro-WEDM is shown in Fig.1. When the electrode wire makes continuous cycle of movement side of a continuous cycle of movement along the guided wheel, it also makes feed motion relative to the workpiece according to the NC instruction in the XY plane, carving narrow slits on the workpiece, as shown in Fig.1a). Discharge gap of micro-WEDM is shown in Fig.1b), a line of discharge occurs on the contact surface of the electrode wire and the workpiece, so working efficiency of micro-WEDM is higher than that of micro-EDM, suitable for the machining parts with high slenderness ratio.



a) micro-WEDM b) discharge gap

Fig.1 Sketch of micro-WEDM

Microelectrode array fabrication by micro-WEDM is different with traditional micro-WEDM, the technology process includes two machining steps, as Fig.2 shows. First, the workpiece, which would be cut to form the micro electrode array, is set horizontally on the work table. The wire moves according to given track with the same offset determined previously by CNC system, and then one of the sides of the workpiece is first cut to obtain thin slices of the micro electrode array as shown in Fig.2a). Subsequently, the holder for workpiece is rotated 90◦ on axes of itself, with respect to the worktable, then the other side is cut by using the same cutting mode. Finally, the microelectrode array is obtained, as shown in Fig.2b).



a) b)

Fig.2 Sketch of microelectrode-array fabrication by WEDM.

3. Fabrication Results of Microelectrode Array by Micro-WEDM

Through analyzing experiment data, optimal experiment parameters, such as open voltage 120V, setting peak current at level 1, discharge duration at level 4 and servo feed rate at 0.2mm/min, are applied. Then a 10×10 electrode array with squared section of is machined as shown in Fig.3, the material is alloyed steel(28Cu12ZnSiAl). The width of squared section for each electrode is about 80μm, the high is about 1000μm and distance between neighborhood electrodes is about 300μm. The other 10×10 micro-electrode array is shown in Fig.4, the material is high-speed steel, the width of squared section for each electrode is about 30μm, the high is about 600μm and the distance between neighborhood electrodes is about 70μm.

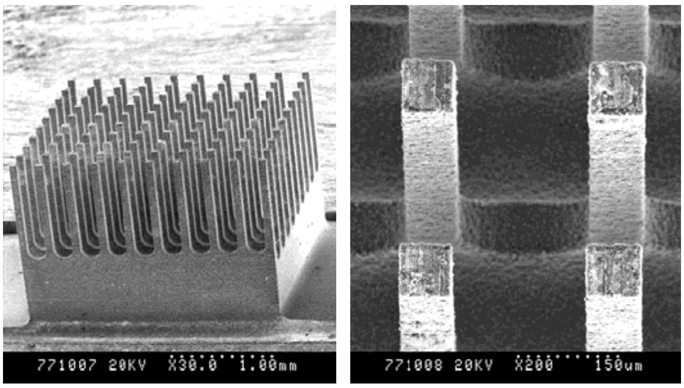


Fig.3 SEM photographs of example by WEDM

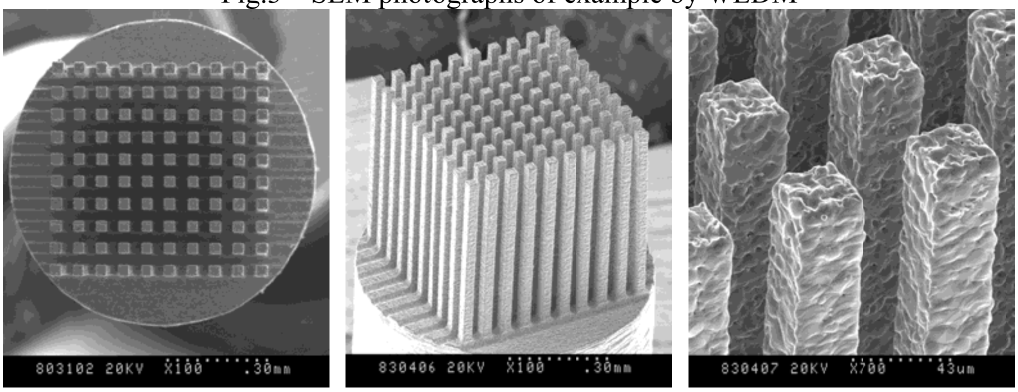


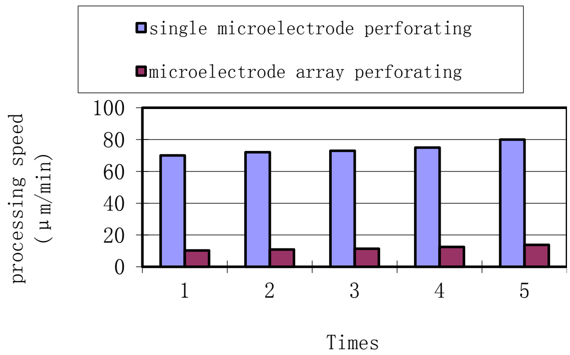
Fig. 4. SEM photographs of example by micro-WEDM.

The obtained microelectrode array has good coaxiality and surface quality due to decreasing open voltage and peak current to decrease per pulse power energy so as to improve machining quality and increasing discharge duration to guarantee machining stability.

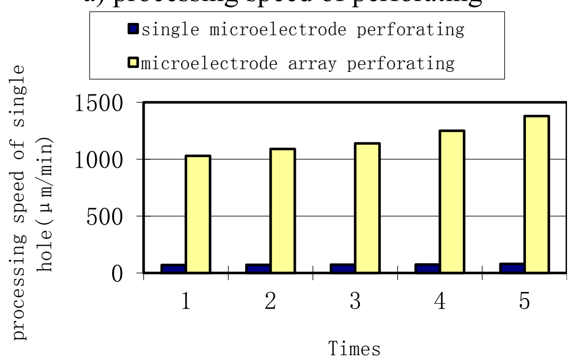
4. Comparative Study for the efficiency of micro-hole fabricated by single electrode or microelectrode array by micro-EDM

The processing efficiency is the key to economic analysis, reducing the processing efficiency can reduce costs. The preceding analysis shows that micro-hole array can be fabricated by a single microelectrode or microelectrode array, so it is necessary of both processing efficiency are compared. The following experiment was carried on by a single electrode and 10 × 10 electrode array with the diameter of 30μm.

Fixing other process parameters, single microelectrode and microelectrode array fabricated holes in tool steel plate of 50μm thick. The processing speeds are shown in Figure.6, the average processing speed of single microelectrode perforated is 74μm/min and the average processing speed of microelectrode array perforated is 12μm/min, a difference of six times, as Figure.5 (a) shows. But for perforating a single hole, the average processing speed of microelectrode array is 1200μm/min, is 16 times than that of t single-electrode, as Figure.5 (b) shows.



a) processing speed of perforating



b) processing speed of single hole

Fig. 5. Efficiency of micro-hole fabrication by single microelectrode and microelectrode array

From Fig.6 it is known that the processing speed for fabricating single hole by microelectrode array is much higher than that by single microelectrode, which is caused by low-frequency response of the spindle servo-driven and the inertia of motion mechanism. The frequency response of motion mechanism driven by DC servo motor is very low, between 20Hz ~ 40Hz, the frequency response of the linear motor is less than 100Hz, after the discharge state detection card has detected that discharge gap is open or short circuit, the feed or rollback command is issued, the spindle begins to act in a few milliseconds and completing the movement requires at least tens of milliseconds. Pulse cycle is less than 100μs as calculated according to the RC pulse power circuit constants of EDM, so the charge and discharge frequency is above 10 KHz. In this way, the pulse power cycle frequency is at least several hundred times higher than the spindle movement response frequency. Single-electrode length of the microelectrode array can not be completely uniform, clamping error and the surface quality of perforated plate electrode are also difficult to guarantee the perforated plane in a horizontal plane, the spark discharge occurred at the poles at the nearest, so when the 10 × 10 array electrode feed down into to the punch, discharge point shifts back and forth continuously according to the distance from the 100 electrodes to the plate electrode, it is greatly reducing the open time. Compared to the single electrode processing, its discharge gap is in the states of short-circuit and open-circuit frequently, the processing efficiency of fabricating holes by microelectrode array is much higher.

Micro-hole array are processed on a self-developed precision micro-EDM machine tool by using microelectrode array obtained above. Machining experiment parameters are listed as follows. Open voltage is set at 60V, discharge capacitor is set at 0 level. Work-piece is set as anode and electrode is set as cathode for consideration of polarity affect. Value of periodic jump-down is 1.5mm/5s. Then 10×10 micro squared holes with about 50μm diameter of each hole are machined on 65Mn sheet with 80μm width. The sample is shown in Fig. 6.

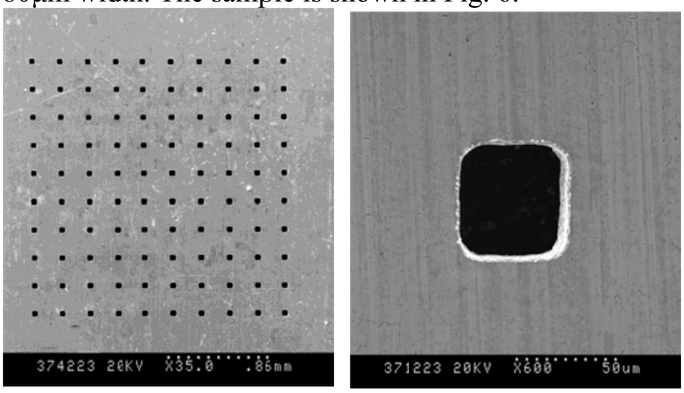


Fig. 6 SEM photographs of 10×10 micro-hole array

In the micro-EDM process decreasing per pulse power energy is to minimize stable discharge gap farther to improve shape precision and the appropriate control strategy of periodic jump-down is to guarantee stability of machining process. The obtained micro-hole array also have good coaxially and shape precision. The smoothed corner of squared hole is resulted by concentration of discharge location.

5. Technologic Characteristics and influence factors of EMM precision

It is convenient and high efficient to fabricate micro-holes in batch with micro-electrode array by EMM, so machining precision of EMM is much important for micro-holes fabrication. There are many influence factors of machining precision such as parameters of the machining gap, voltage drop, electrolyte conductivity, feeding rate, current efficiency and so on. Therefore, those influence factors of EMM should be researched. Then the result can be used to the instruction of the industrial production, and the development of EMM in micro-holes array machining region will be wide.

EMM error of Micro-hole array fabrication can be divided into duplication error and repeated error according to its technology characteristics, duplication error refers to the error between micro-hole and micro-electrode in figure and dimension, repeated error refers to the error between each microhole in figure and dimension. The machining gap is the core factor which can influence precision directly. The size of the gap influences the material elimination of workpiece greatly. When the machining gap is very small, the feedback action is very strong, and figuration precision is high, so the effect of micromachining is better. In the EMM process, the machining gap is exist between tool cathode and workpiece anode, that is the root cause of duplication error and repeated error. Changes and its uneven distribution of the electric field, the flow field and the electrochemical field between the poles, are the root reason for changes of the machining gap, it is the function based on time and space. Equilibrium formula of the machining gap for EMM is as following[11]:

$$\Delta = \eta \omega \kappa \frac{U}{v} \qquad (1)$$

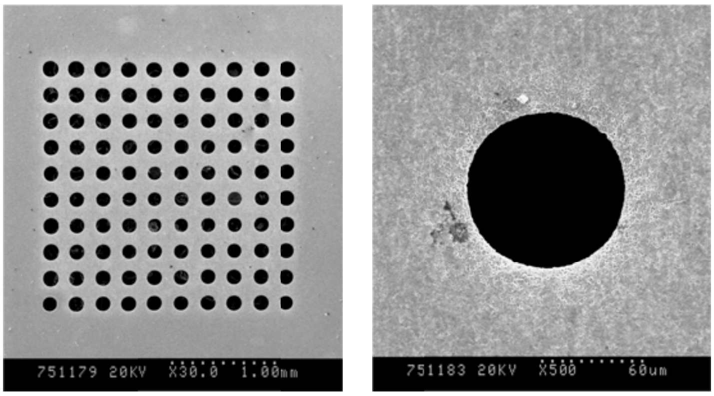
In Eq.1, D——machining gap for EMM(mm), U——voltage drop of gap electrolyte, h —— current efficiency, w ——volume electrochemical equivalent, k ——Electrolyte conductivity of electrolyzed material(S/mm), v——feeding rate of electrode.
It can be got by Eq.1:

$$d\Delta = \Delta\left(\frac{d\eta}{\eta} + \frac{dU}{U} + \frac{d\kappa}{\kappa} - \frac{dv}{v}\right) \qquad (2)$$

It can be seen that the working voltage is also very important process parameter in EMM. The higher working voltage result in the bigger machining gap, corresponding when the machining error is bigger, micro-hole machining accuracy will be worse.

6. Fabrication Result of Micro-hole array by EMM

Then 10×10 micro-hole array is fabricated by 10×10 square micro-electrode array of 40μm high by EMM, the diameter of single hole is about 100μm and deep is 30μm, as shown in Fig.7. The material of micro-hole array is stainless steel(1Cr21Ni5Ti) and the material of micro-electrode array is red copper. The processing conditions are shown as following: high-frequency pulse power supply, working voltage is 5V, electrolyte is 15g/L of $NaClO_3$, duty ratio is 0.5, feeding rate of 0.5μm/s, the workpiece is anode and the tool electrode is cathode in the working process.



a) micro-hole array b) single micro-hole

Fig.7. SEM photographs of example EMM machined.

Affected by duplication error and repeated error of EMM, the micro-hole array show obvious circular. In the process of EMM, the machining gap between tool cathode and workpiece anode is the root cause leading to the error. EMM error of Micro-hole array can be divided into duplication error and repeated error. The distribution of electric field strength and scattered erosion are the most important causation resulting in duplication error. There is stray electric-field existing on electrode side, making scattered erosion to workpiece, impacting micro-hole forming processing precision, the extent of scattered erosion becomes serious with processing time growing, that is showed as phenomenon of sharp corner turning round and the phenomenon is observed carefully by experiments. while the accumulation of air bubbles in the processing region leads to the emergence of repeated error.

7. Conclusion

In this paper, a new technology of microelectrode array and micro-hole array fabricated by combined micro-WEDM and EMM(Electrochemical micromachining) was successfully developed. Process of Micro-WEDM(wire electrical discharge grinding) technology for microelectrode array fabrication is assessed. 10×10 micro-electrode arrays are got, the width of squared section for each electrode is about 30μm, the high is about 600μm and the distance between neighborhood electrodes is about 70μm, and 10×10 square micro-hole arrays fabricated by these microelectrode arrays are got by micro-EDM, the diameter of each hole is about 50μm and the width is about 80μm. Working efficiency of using microelectrode array and single electrode to machine micro-hole array by Micro-EDM is compared, the former has higher efficiency. Then 10×10 micro-hole arrays are fabricated by 10×10 square micro-electrode array of 40μm high by EMM, the diameter of single hole is about 100μm and deep is 30μm. Affected by duplication error and repeated error of EMM, the micro-hole array show obvious circular. New technology of large scale microelectrode array and micro-hole array fabricated by combined micro-WEDM and EMM is proved to be feasible and high efficient.

Acknowledgments

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