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Micro/Meso-scale Shapes Machining by Micro EDM Process

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ABSTRACT

Among the micro machining techniques, micro EDM is generally used for machining micro holes, pockets, and micro structures on difficult-cut-materials. Micro EDM parameters such as applied voltage, capacitance, peak current, pulse width, duration time are very important to fabricate the tool electrode and produce the micro structures. Developed micro EDM machine is composed of a 3-axis driving system and RC circuit equipped with pulse generator. In this paper, using micro EDM machine, the characteristics of micro EDM process are investigated and it is applied to micro holes, slots, and pockets machining. Through experiments, relations between machined surface and voltages and between MRR and feedrate are investigated. Also the trends of tool wear are investigated in case of hole and slot machining.

Key Words: Micro EDM, WEDG (Wire Electro Discharge Grinding), Tool Electrode, Micro Hole, Micro Structure

1. Introduction

With the rapid progress of machining technology, product becomes smaller, functional, and more diverse. Especially, a demand for micro/meso-scale product is increasing with the development of semiconductor, aerospace and bio technology.

There are many micro machining techniques such as micro drilling, micro milling, laser machining, micro EDM, micro ECM, lithography, and so on. Etching, deposition, and lithography used in fabrication of semiconductor parts are adequate to machine surface structures for mass production. However, in spite of this advantage, there are some limitations in these micro machining techniques. It is very difficult to machine three dimensional structures due to its machining mechanism. In addition, materials which can be machined are often limited only to silicon. As for lithography, it can fabricate mechanical parts with very high aspect ratios, but it has a drawback that curvature machining is almost impossible. For these reasons, many researchers are studying on miniaturizing conventional machine tools and machining micro structures with widening the range of materials to be machined. But it is very difficult to fabricate the micro tools and the cost of production is very expensive. In addition, because tool electrode has a low stiffness and its cutting capability has limitation due to cutting force, shape accuracy and cutting capability which users need cannot be acquired.

Micro EDM process is a proper machining method to overcome these defects, Fig. 1 illustrates a comparison of the machining range of conventional machining and micro machining. Recently, micro machining technology is being widened to nanometer ranges.

Precision micro holes required for gas and liquid orifices in aerospace and medical applications, pinholes for x-ray and nuclear fusion measurements, ink-jet printer nozzles and electron beam gun apertures can be fabricated with high precision accuracy and with surface roughness smaller than 0.1μm using the micro EDM process[1].

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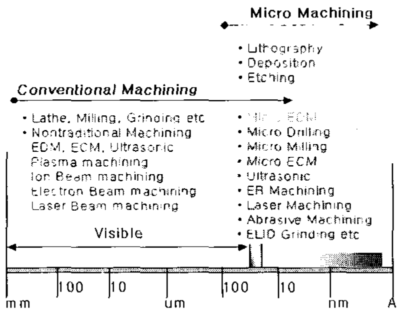


Fig. 1 Machining range between conventional and micro machining

Micro holes can usually machined to a depth of 1 to 5 times the hole diameter. The diameter of the micro hole that can be machined by micro EDM is about 5-300μm. The depth and the diameter of micro holes obtained by micro EDM and other methods[2] are depicted in Fig. 2.

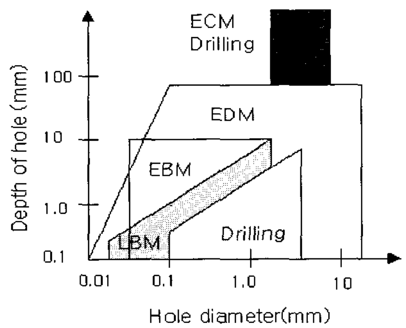


Fig. 2 Aspect ratios according to the machining method

Taking into account the studies of domestic and foreign researchers, Kholodnov[3] has studied about the influence of capacitance on overcut, Jeswani[4] has made an equation of overcut due to discharge voltage, capacitance, diameter of tool, and depth of hole from experiment. Masuzawa[5,6] suggested a three dimensional machining method in micro EDM using a simple shaped electrode and they fabricated a three dimensional micro mold of the shape of a car with 1 mm length and few hundreds micrometer width. Chu[7] has researched on micro machining by combination of EDM and ultrasonic machining.

In this paper, using an EDM circuit equipped with pulse generator to modulate pulse width and developed micro EDM machine, experiments are performed for machining micro/meso-scaled shapes such as micro holes, slots, and pockets by Micro EDM process. Through experimental results, how EDM parameters such as discharge voltage, peak current, capacitance, and pulse width have influence on the machining characteristics, material removal rate and tool wear characteristics are investigated and discussed.

2. Theory

2.1 The principles of EDM

Fig. 3 illustrates the principle of material removal mechanism in EDM process. Plasma channels towards workpiece are created during the discharge and high speed electrons come into collision with the workpiece. At that time, the temperature on the workpiece surface becomes high locally in a moment and yielding stress of that location becomes lower so that materials on the surface are removed and create debris. The molten debris are carried away from the gap between the tool and the workpiece by difference of pressure and unremoved debris can be the cause of a secondary discharge.

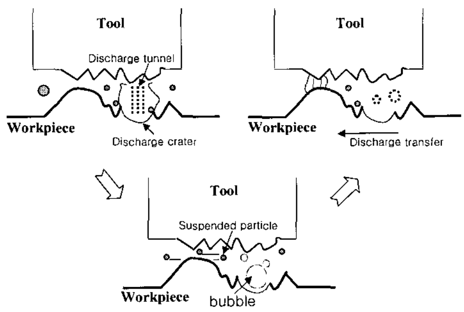


Fig. 3 Principle of EDM

2.2 The principle of WEDG

The tool electrode can be created either by etching, grinding, lithography process. However, when the fabricated tool is chucked on the machine, an alignment error between tool center and spindle center and run-out error of tool which has an influence on the variation of the discharge gap occurs and cause serious problems in micro machining and assembly of micro parts. The method to solve these problems is WEDG[6] (wire electro discharge grinding) that is an on-machine tool making method by a wire. Fig. 4 shows the principle of WEDG and Fig. 5 shows an example of the fabricated tool by WEDG. Minimum 5.5 micrometer tool was fabricated by WEDG from experiment.

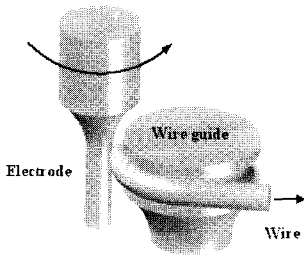


Fig. 4 The principle of WEDG

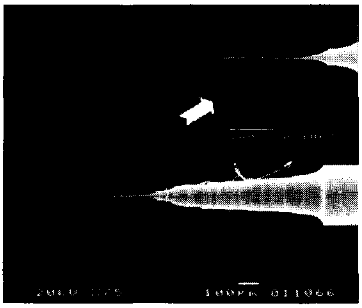
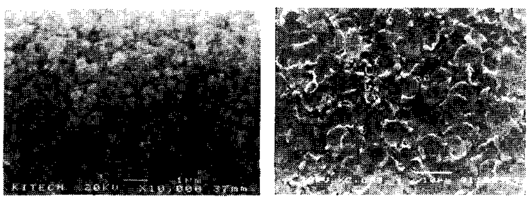


Fig. 5 Fabricated electrode (φ10 μm, length: 200μm)

In general, the compressive stress acts on the surface machined by cutting and the residual stress remains in the surface. On the other hand, in the case of EDM, tensile stress acts on the surface. Another problem of EDM is that the deformed surface is created at high temperature. The good machining is to decrease the deformed layer and surface roughness due to discharge crater to the required level. Fig. 6 shows the states of the surface in the case of grinding and EDM Machining. The surface by discharge machining is not good as a ground surface.



(a) Ground surface (b) WEDG surface

Fig.6 Machined surface

3. Experimental Setup

3.1 EDM circuit

The EDM circuit used in this experiment is composed of a basic RC circuit. The characteristics of this RC circuit are that peak current I_P is high and discharge width τ_P of the current is short. Because of this reason, the RC circuit is used for fine EDM machining. This circuit has a drawback that arc discharge occurs and this leads to unstable machining.

Fig. 7 shows a developed EDM circuit built in micro EDM machine. The input power supply can be regulated from 40V to 300V and the acceptable current value is a maximum 1A. The PWM circuit built into the RC circuit is designed to control pulse width of 200ns per each step. This circuit can control the on-time and off-time pulse duration. Fig. 8 illustrates pulse width controlled by PWM.

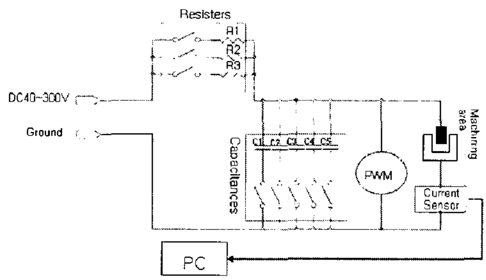


Fig. 7 RC circuits equipped with PWM

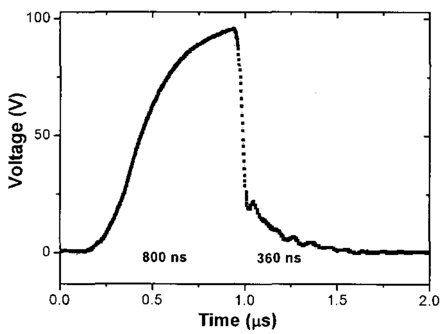


Fig. 8 Pulse wave controlled by PWM

The RC circuit with PWM has an advantage that can restore insulation artificially between tool and workpiece by compulsory termination of voltage input.

Table 1 shows resistors, input voltage, controllable pulse width, and capacitance built in the EDM circuit. In case of resistor, two types of resistors are used. One is a metal blade resistor and it has very low inductance. Another is a coil resistor and it has a high inductance so that the actual voltage between tool and workpiece rises to 4-6 times as high as that of input voltage. As the result, the machining energy increases instantaneously and the efficiency of machining become high. The material of used tool is WC and the workpiece is tungsten and SUS304.

Table 1 The specification of EDM circuit

Units	Specification
Power supply (V)	DC 0~300
Resistors (Ω)	560, 800, 1000 (metal blade resistors) 100, 200, 300, 500, 1000 (coil resistors)
Capacitors (pF)	1, 10, 30, 50, 75, 100, 500, 680,1000, 5000
PWM (ns)	600~4000

3.2 The configuration of machine

The experimental equipments, which can fabricate micro tool by WEDG and machine micro holes and shapes with fabricated electrodes, are depicted in Fig. 9.

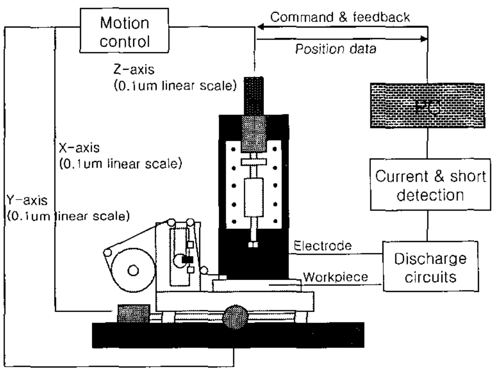


Fig. 9 Schematic diagram of micro EDM machine

The developed machine is composed of a 3-axis driving system driven by the stepping motor and has a spindle and WEDG system. In WEDG system, to keep tension of wire, the spring is built in wire Bobbin driving parts and the tension of the wire is controlled by spring force. To acquire feed accuracy, a linear encoder that has a 0.1μm resolution is attached to each axis. The motion of the machine is controlled by a MMC (multi motion controller) built in PC. And, G-code program is used in machining.

4. Results and Discussion

4.1 Fabrication of the tool electrode

Fig. 10 illustrates fabricated tool electrodes by WEDG. A tool electrode with a minimum of 5.5 μm diameter and 200μm length is fabricated through the experiment. An experimental design was used to control the size of the tool electrode and fabricate the required tool.

In case of 140V and 200V input voltage, the surface of the machined tool electrode is depicted and compared in Fig. 11.

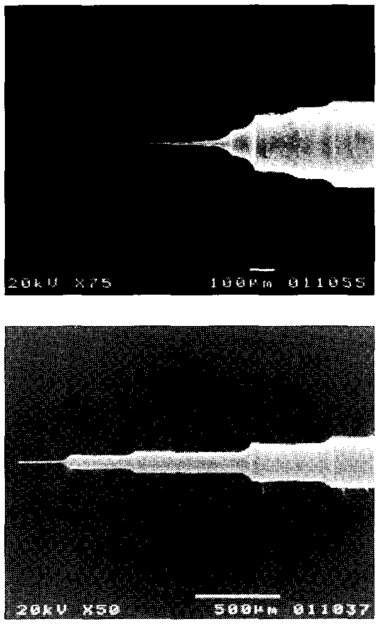


Fig. 10 Tool electrode machined by WEDG

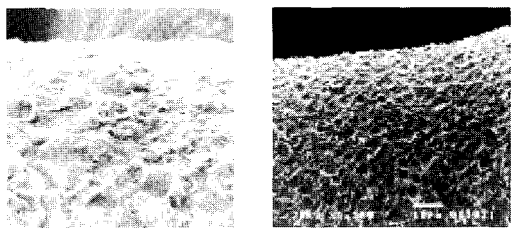


Fig. 11 Surfaces of tool electrodes machined by WEDG

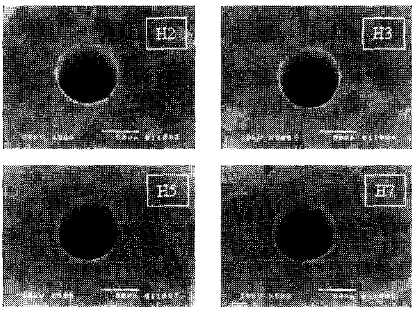
With input voltage, the energy into the workpiece has a big difference and this affects the radius of the plasma channels. Normal size of the plasma channel is about 0.5 μm and this radius varies according to discharge energy.

4.2 Micro-hole machining

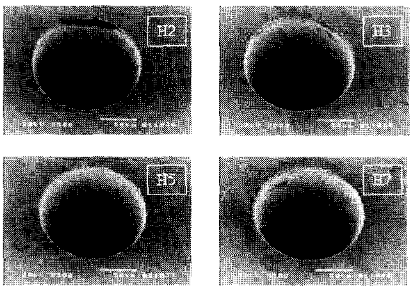
Using 50μm and 100μm tools, micro hole machining is carried out. The machining conditions are depicted in Table 2. Micro holes are machined at each condition and the diameters of holes' entrance and exit are measured. Also, the surface status of the side walls of machined holes are observed through the SEM image and discussed.

Table 2 The machining conditions of EDM drilling hole

Hole No.	Capacitance (pF)	Voltage (V)	Feedrates (μm/s)	Resistor (Ω)	Spindle speed (rpm)
H1	1	120	0.1	1000	500
H2	10	120	0.1	1000	500
H3	50	120	0.1	1000	500
H4	100	120	0.1	1000	500
H5	10	120	0.1	560	500
H6	10	120	0.1	800	500
H7	10	140	0.1	1000	500
H8	10	100	0.1	1000	500



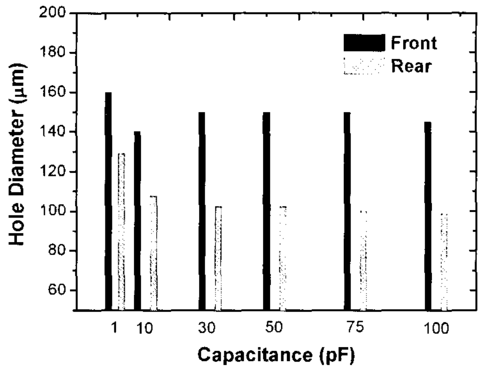
(a) 50μm tool electrode



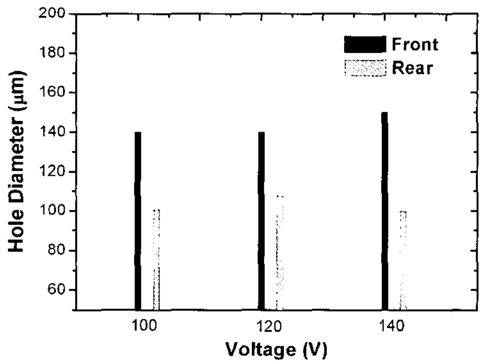
(b) 100μm tool electrode

Fig. 12 The SEM photograph of machined hole

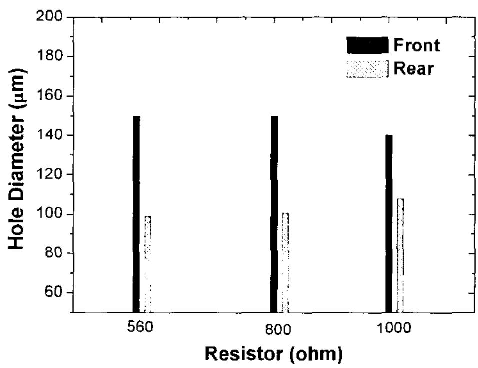
Fig. 12 illustrates SEM image of holes machined according to the conditions of Table 2 with 50μm and 100μm tool. The thickness of machined workpiece is 200μm and the material is tungsten substrate. The diameter of machined holes is a little bigger than that of tools. This happens due to overcut by side wall discharge.



(a) Variation of the hole diameter with capacitors



(b) Variation of the hole diameter with voltages



(c) Variation of the hole diameters with resistors

Fig. 13 Variation of the hole diameter according to machining conditions

Fig. 13 illustrates diameters of machined holes varies according to (a) capacitances, (b) voltages, and (c) resistors using 100μm tool. In case of 10pF, 100V, and 1000 Ω , the overcut is smallest at each experiment. The diameters of exits at each condition are almost 100 μm except only 1pF capacitor condition. When input voltage and current is large, the entrance diameters are big. In case of capacitance, the entrance diameter is smallest in 10pF.

The inside surface of machined holes are shown at Fig. 14. When capacitance is 10pF, the inside surface is better than when other capacitor is used.

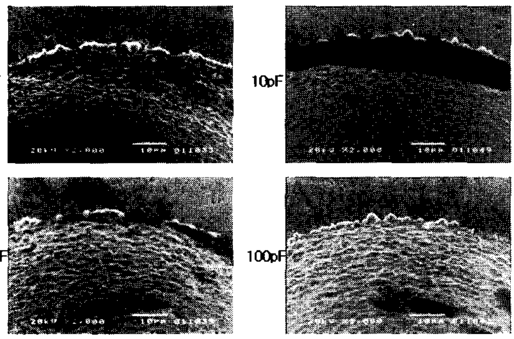
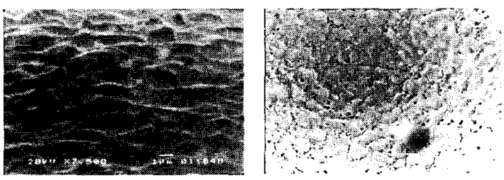


Fig. 14 Inner wall surfaces of machined hole

Fig. 15 illustrates the inside wall and the bottom surface of machined holes. The surface bottom has a normal crater shape. In case of the inside wall, the surface has a wave pattern. This surface is created by scratch behavior of debris like abrasive particle.



(a) Side wall surface (b) Bottom surface

Fig. 15 Surfaces of a machined pocket hole

Using a 150μm tool, when the hole is machined on the 100μm thickness stainless steel, tool wear trends are depicted in Fig. 16 and Fig. 17. Input voltage is 100V and spindle speed is 250rpm. When resistor value is 560 Ω , that is to say, in case of high current and low capacitance, the tool wear rate is small. Because the discharge pressure is high at high discharge current, and this results in good flushing activity of dielectric debris, which are carried away well out of the hole.

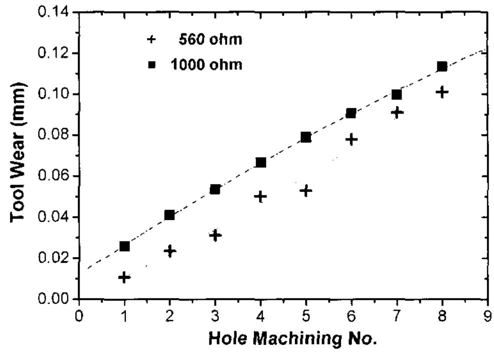


Fig. 16 Tool wear trend with resistors

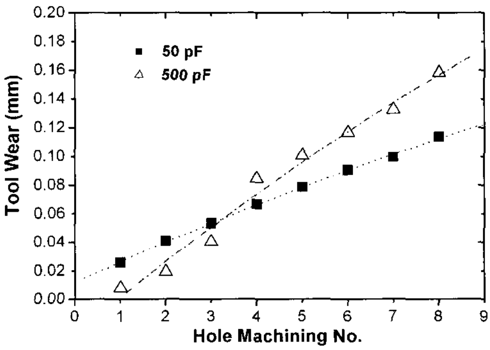


Fig. 17 Tool wear trend with capacitors

4.3 Slot and pocket machining

Slot and pocket machining is indispensable for 3D micro-scaled shape machining. Slot machining that the depth of each slot is 3-5μm and machining length is 900μm is performed. The material of the workpiece is SUS304. When capacitance is 1pF and 50pF for slot machining, the variation of the MRR is depicted in Fig. 18. As feedrates are faster, the MRR also increases. The MRR of 1pF has always larger result than that of 50pF. When capacitance is small, the MRR is higher. If capacitance is small, energy input by single discharge and discharge time is also small. So the frequent sparks occur for machining. As the result, total energy enters into workpiece at same time is more than that of high capacitance. Fig. 19 shows the depth of slots and tool wear according to on-time and feedrate. Tool wear has a trend to be small with increments of feedrate and when feedrate is 0.5μm/s, machined depth is almost constant. When on-time is long, tool wear is small and machined depth does not vary according to feedrate at low feed speed.

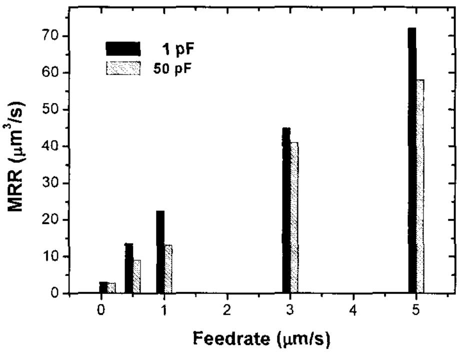


Fig. 18 MRR variation with federates

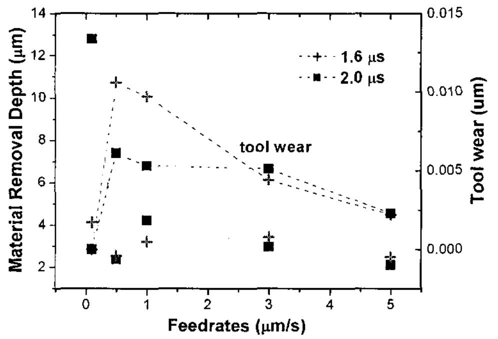


Fig. 19 Material removal depth (MRD) and tool wear variation with federates

Fig. 20 Pocket machining

Fig. 20 illustrates the results of pocket machining. In pocket shape, as a result of the effect of tool wear, the machined depth has not reached the desired depth. It is indispensable to compensate for tool wear for three dimensional micro/meso-scaled shapes machining.

5. Conclusions

The following results were obtained from micro hole machining, slot machining, and pocket machining experiment using developed micro EDM machine.

1. In WEDG machining, input voltage influences on the surface state of a machined tool very much. When the voltage is low, the surface is better. Input voltage has a close relation with discharge current and the radius of the plasma channel and increases with increment of input voltage. The size of the plasma channel decides the quality of the machined surface.
2. In slot machining, when the feedrate is fast and capacitance is small, the MRR is high. If feedrate is 0.5 μm/s, machined depth keeps an almost constant value and tool wear decreases with increment of feedrate. When on-time is long; the tool weaı is small.
3. With the occurrence of tool wear due to discharge energy in pocket machining, the machining accuracy becomes worse. To achieve the good shape accuracy tool wear has to be compensated.

References

1. Dario, P., Carrozza, M.C., "Non-traditional Technologies for Micro fabrication," Journal of Micromech. Microeng, Vol. 5, pp. 64-71, 1995.
2. Snoeys, R., Staelens, F., Dekeyser, W., "Current Trends in Non-Conventional Material Removal Processes," CIRP, Vol. 35, No.2, pp. 467-480, 1986.
3. Kholodnov, E., "Electrospark Machining of Metals," Consultants Bureau, Vol. 2, pp. 120-121, 1964.
4. Jeswani, M. J., "Small Hole Drilling in EDM," Int. J. Mach. Tool Des. Res., Vol. 19, pp. 165-169, 1979.
5. Masaki, T., Kavata, K. and Masuzawa, T., "Micro Electro-Discharge Machining and Its Applications," Proc. MEMS (Napa Valley, CA), pp. 21-26, 1990.
6. Masuzawa, T., Fujino, M., "Wire Electro-Discharge Grinding for Micro Machining," Annals of the CIRP, Vol. 34, pp. 431-434, 1985.
7. Chu, J.N., Kim, G.M., Kim, S.Y., "Fabrication of Micro-Shapes using EDM and Ultrasonic Machining," Journal of the KSPE, Vol. 17, No. 7, pp. 20-27, 2000.