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Development of Multi-Point Micro-Punch: The Effects of Gold Plating on Discharge Time and Punch Surface.

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Abstract

The continued demand for micro-hole and slots is one of the driving forces behind this research. Coupled with this are successes gained in developing a single-point micro-punching unit. In this paper a multi-point micro punch and die were developed using tungsten and tool-steel as the punch material. The process of electric discharge machining (EDM) was used to produce the punch and die. The punches were machined from tungsten and tool-steel rods by wire electric discharge machining (WEDM) and the die holes were made using the punch as the electrode. The punch and die were set on a micro die-set and the holes were machined on a newly developed desktop EDM machine. The die-set was then transferred to a micro-press and the punching process was conducted. Experiments to produce 50-69 µm square micro-holes on 50 µm thick aluminum, 30 µm thick copper and 20 µm thick stainless steel foils were conducted and tungsten was chosen as the best material for making the punch. After the EDM process it was discovered that the surfaces of the punch were round and had to be flattened by reverse EDM. The effects of gold plating the micro-punches were examined as a means of reducing the discharge processing time and the rounding of the punch surface. With the aid of microscopes the holes produced were confirmed as clean and the sheared surfaces smooth. The holes produced by the gold plated punches were much cleaner than those produced by the non-gold plated punches. Consequently, the process of flattening after machining the die holes was eliminated and processing time was significantly reduced. The punch tools showed no signs of defect or deformation even after repeated punching.

Keywords: Multi-Point Punch; Gold Plating; Micro-Die Set; EDM; Clearance

1. Introduction*

The ongoing development in micro and high density products has led to continued research and development in the field of micro-hole technology. Some of the more popular research fields include EDM machining, vibration EDM machining [1], micro-punching using SiC fiber and laser micro-hole machining processes [2-4]. EDM and laser processes, which are currently the leading manufacturing methods of producing micro-holes and slots, are limited because of production cost, lengthy processing time and limitations with the materials that can be used in these processes. In addition, these methods have faced some amount of difficulties in applying them across various industries because they are not suited for mass production of micro-holes [2]. On the other hand, punching which is a deformation process has remained the most preferred method of mass production [5-6].

Although Chern and Wang [4] have developed a micro-forming and micro-punching system, alignment devices to ensure precise centering are needed because both punch and die were made separately. This can result in increases in production time and processing cost, and the possibility of miss alignment still remains a cause for concern. In this research the development of a multi-point punch and die set was examined. Tungsten and tool-steel were used as the material for making the punch and steel (S45C in JIS) for making the die. Tungsten was chosen as the preferred material because of its availability, its properties, mechanical as well as electrical, and its ability to punch various materials successfully. Table 1 shows the mechanical properties of tungsten. It is well documented that tungsten is widely used successfully across various manufacturing industries and in many researched and developed processes as micro rods to produce micro holes and for micro-hole drilling [7-8]. Not only is tungsten the most popular material of choice for micro rods and drills, but also in the other researches that have sought to develop micro punching systems[18 Chern and Chaung]. Lim, Lim and Kim [9] using electrochemical etching have developed a tungsten micro-punch for micro nozzles. Electrochemical etching is traditionally used to produce very sharp probes for atomic force microscopy or in the scanning of tunneling microscopy [10-11]. By using this process they were able to produce multiple punches cheaply and simultaneously. However, there is no evidence that this method can be employed to mechanical micro punching. Other researchers such as Joo, Rhim and Oh [12] developed a micro-hole mechanical punching process but

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again expensive alignment devices were also needed with this process. In this case a machine vision system was developed and used to achieve accuracy within 1 µm. In addition to increased cost, addition time was also required to obtain proper alignment between punch and die, and misalignment is still possible.

Table I. Mechanical properties of tungsten.

Property	Value
Atomic weight	183.85 g/g atom
Density	19.25 g/cm^3
Melting Point	3410ºC
Ultimate strength	1510 MPa
Young's modulus	411 GPa

The multi-point punch is a development of the micro-punching system developed by Mori [2], one of the authors of this paper, using SiC fiber as the material for the punching tool. In that research it was possible to conquer some of the difficulties of alignment, however, continued research was necessary to make the system applicable to the industry. The decision to develop a multi-point punch was based on the success of developing a single point punch using similar methodologies, systems and processes in earlier experiments. This multi-point punching system will be better able to meet the ongoing demand for mass production of micro holes and slots in the various manufacturing sectors. Areas of demand include the miniaturization of electronic components for micro-systems technologies (MST) and micro-electromechanical systems (MEMS). Pins for IC-carriers, fasteners, micro-screws and contact springs, are some of the typical parts. Other areas of application include medical equipments, sensor technology, telecommunications and high-tech security systems [4], [13-14].

2. Experiment Method

2.1. Making of Punch

The multi-point micro-punch was made by wire EDM (WEDM) using the Mitsubishi DIAX FX10 EDM machine. Figure 1 shows the machining process of the punch. Before the punch points were machined one end of the round bar was machined by WEDM into a square prism of height 2.5 mm and square edges of 1.5 mm x 1.5 mm, as shown in Figure 1(a). Next, using the wire electrode the four point punch was machined in two stages as shown in Figure 1. In Figure 1(c to f), the center gutter was machined by the 200µm wire with a discharge gap of 20µm between the wire and inner punch walls. The wire electrode was then off-centered a distance of 600µm from the center and machined as shown in Figure 1(d).

The work was then rotated 90º and the processes of (c) and (d) were repeated. The work was then returned to its original position. This is the rough machining stage. The electrode wire was again off-centered by 80µm as shown in Figure 1(e), and machining done on the inner portions of the punch walls as shown. In Figure 1(f) finish machining of the outer sections of the punch points was done by off-centering the electrode wire by a distance of 370µm. The work was then rotated by 90ºand the processes of (e) and (f) repeated. The direction of machining is indicated by the arrows affixed to each drawing. Careful machining was done to ensure even distribution and parallelism between the punch-points. This is of extreme importance because the punch was also used as the electrode for making the die holes and unevenness would increase the discharge processing time, which leads to unequal material removal from the punch point surfaces.

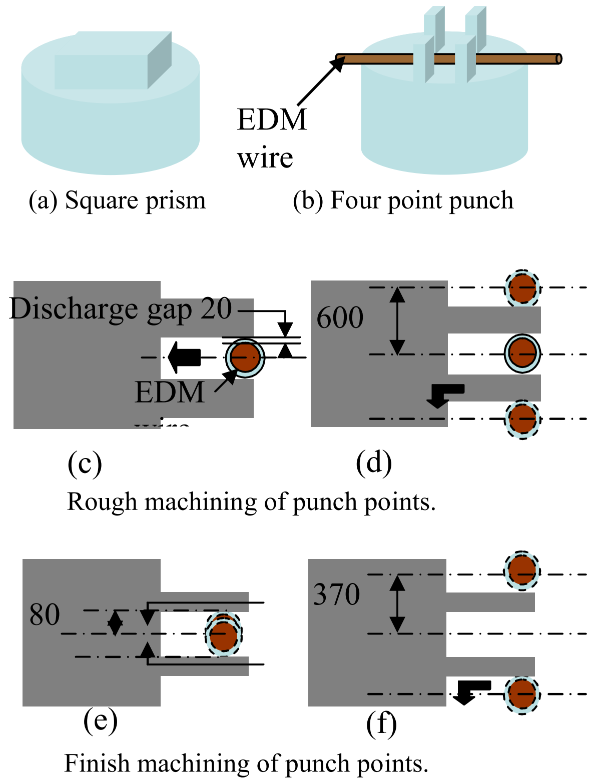


Figure 1. Punch making process.

2.2. Making of Die

Figure 2 shows the die making process. First a gutter of about 1.5 mm depth and 2 mm wide was cut in a plane machined from hard steel in the shape shown in (a). The tip of the gutter was machined by end mill to a width of 1 mm. The die surface was then polished to obtained a thickness of 20~30µm across the thinnest portion of the face where the hole was machined in (b), using # 2000 emery paper and 0.05µm aluminum powder. The die finished without making the hole was fastened to a micro die-set together with the prescribed micro punch as shown in Figure3. Next the micro die-set was placed into a specially made desktop EDM machine as shown in Figure 4. In this machine the process of Figure 2 (c) in which a die hole was made by electric discharge machining using the micro punch as the electrode was carried out. The holes were machined on the thinnest part of the die and the other portion provided support for the hole. A resistor-capacitor (R-C) circuit was used for the EDM process. This is because the R-C circuit works well for applications that require a low ampere-sparking output and is best for creating fine surface finishes or drilling small precision holes [15]. In order to prevent a large current from flowing through the circuit during short-circuit a large resistance (resistor) was used. This reduced the short-circuit current to acceptable levels. Table 2 shows the discharge processing condition for machining the die holes. During the polishing process of the die surface, care was taken to ensure that it was polished evenly and flat to ensure simultaneous machining of the die holes and material removal from the punch points during the EDM process.

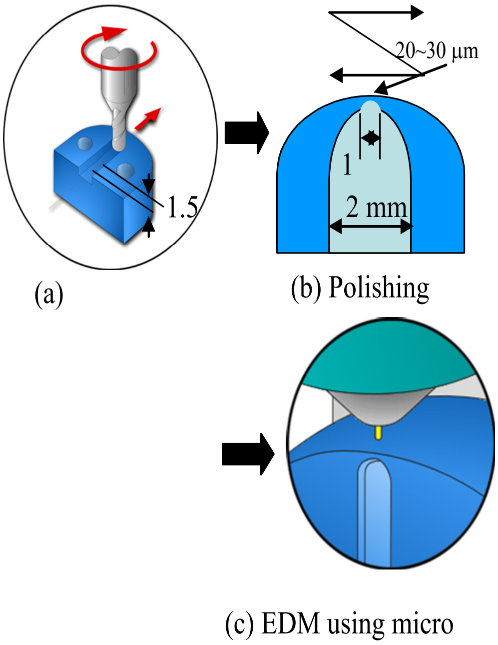


Figure 2. Die making process.

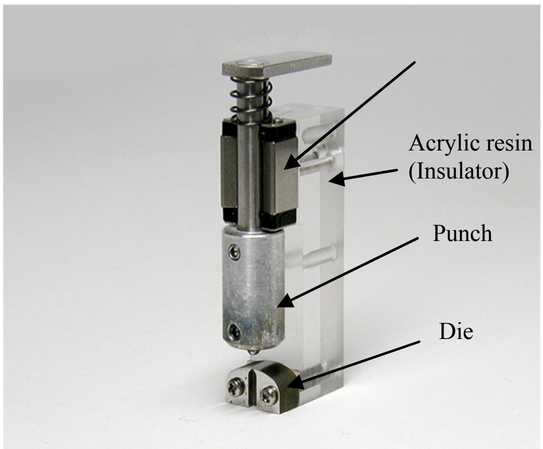


Figure 3. Micro-die set.

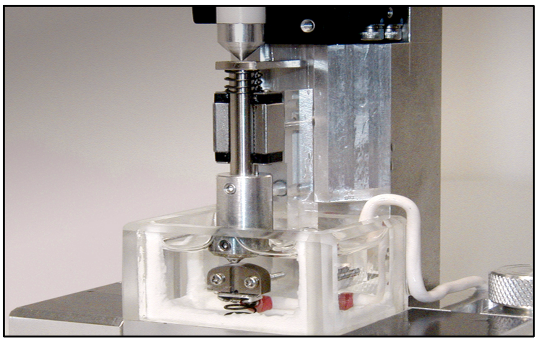


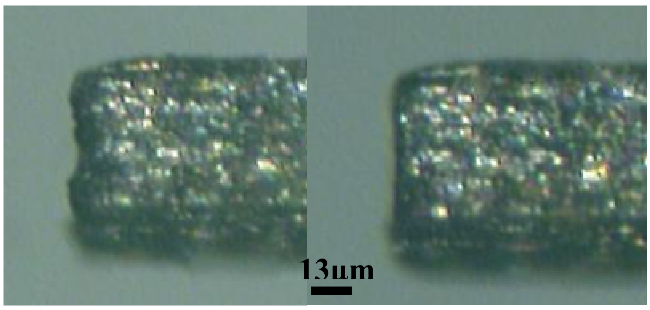
Figure 4. Desk top EDM machine.

Table 2. Electric discharge conditions.

Parameter	Quantity
Capacitance	1000~2000 pF
Voltage	40~45 V
Resistance	200 kΩ
Current	6.15 A
Electric discharge time	14 ~18 hr
Punch diameter	50μm (SK3)/64 μm(W)
Clearance	7.8-8.35μm

2.3. Flattening of Punch Surface

Flattening of the punch tool tip surface was done twice, before and after the EDM process of the die hole. Flattening before the EDM process was done to ensure that all four die holes were made simultaneously. This reduced the discharge processing time and the electrode consumption rate. The second flattening was necessary because after the die holes were machined the edges of the four-point punch appeared slightly round and uneven. However, the surfaces of the punch must be even, flat and acute to ensure that the punch surface satisfies the degree of demand of the cutting surface of a punch tool. If this was not done successful punching would not have been possible and the punch tool would have been adversely affected, as was observed on some occasion during the punching process. Also, if the punching surface of the tool was dull it would lead to unfavorable conditions, for example, long burr formation on the die side of the stock [16]. Flattening was done by reversing the polarity of the work and punch. A piece of 40μm thick copper and a piece of 20μm thick hard steel laminated foil was placed between the die surface and the punch. This increased the rate of material removal from the tool surface, while preventing material removal from the die surface. This process was carried out without separation of punch and die. Therefore the die set was designed so that this operation was possible without affecting the alignment of the punch and die unit. Figure 5 shows the micro-punch tool tip surface before and after the second flattening process.



After EDM After flattening

Figure 5. Micrographs of punch before and after flattening.

2.4. Control and Measurement

The entire punching operation was controlled from a computer. The movement of the punch was controlled by the use of a piezoelectric actuator, connecting the micro punching system to the computer, and the movement of the material to be punched by stepping motor. The laminating

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piezoelectric actuator used provided a maximum displacement of 68µm, and a generating force of 800 N was used for the primary drive. Figure 6 shows the linear relation between direct current voltage (V) and displacement (µm). The punching speed and movement were also controlled by the computer, which was connected to the piezo driver via D/A converter. Three highly precise miniature bearings were used for the guide of the punch. A microscope was used for positioning of the punch and observation of the punching operation.

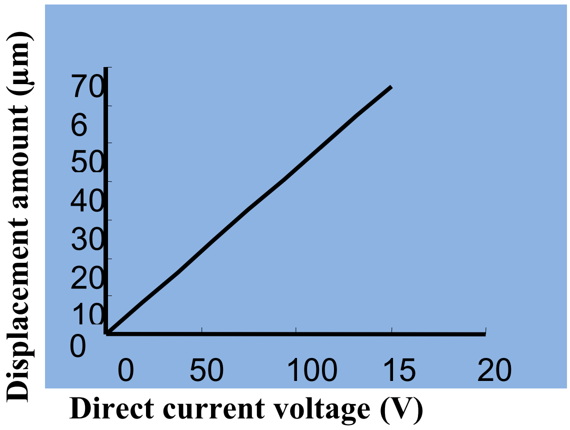


Figure 6. Displacement Vs. Direct Current Voltage.

The movement of the punch agreed with that of the piezoelectric actuator. The coefficient of conversion from piezoelectric driver voltage to punch stroke was 0.45µm /V and the punch movement signals were 10 V (punch stroke of 4.5µm) for a rough feed, and 1 V (0.45µm) for a fine feed. The punch speed was controlled by a change of the piezoelectric drive voltage, and varied from 6.4µm/sec to 3.8 mm/sec. The punching process was carried out at a punch speed of 6.4µm/sec without lubricant. The material feed was set and controlled by stepping motors for both the X and Y axis (movement of 0.1 mm). The material to be punched was secured by way of clamps attached to the X axis.

For this research a direct current voltage of 140V was used, which gave a vertical displacement of approximately 60µm of the punch. This was sufficient as the materials punched were 20µm to 50µm thick and the thickness of the section of the die where the hole was machined is between 20µm to 30µm thick. According to Tarkany [17] over entry of the punch creates excessive wear and can cause slug pulling. The farther a punch enters the more vacuum it creates at withdrawal. This vacuum can pull slugs. If a larger displacement is required this can be achieved by simply increasing the voltage on the piezo controller as illustrated in Figure 6.

2.5. Trial Punching

Punching was done using punches made from tool-steel (SK3) and tungsten (W). Figure 7 shows the average dimension of the tool steel and tungsten punches used in this experiment. Punching was conducted on 20µm and 30µm thick copper, 25µm and 50µm thick aluminum and 20µm thick stainless steel foils. For the tool-steel, punching of the copper and aluminum foils was successful but unsuccessful for the stainless steel foil. Repeated attempts to punch the stainless steel foil resulted in buckling of the punch tool. Figure 8 shows the punched holes of the copper and aluminum foils. After punching of over 500 heats on both the aluminum foils and copper foils, there were no noticeable signs of defects on the punch tool surface that indicated that the tool was breaking down, nor in the shape of the punched holes. From the micrographs, the holes produced appeared free of burrs, cracks and other forms of deformation that would denote poor hole production. The failure in punching the stainless steel foil implied that the result would be the same for materials of similar hardness.

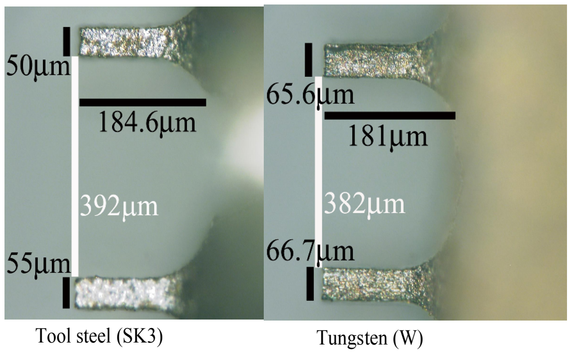


Figure 7. Dimension of punches.

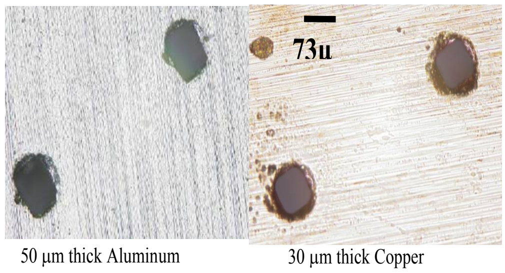


Figure 8. Holes punched by tool-steel punch

For the tungsten punch, trial punching was conducted on the same three materials, as well as on 20µm thick copper and 25µm thick aluminum foils. Except for the 25µm aluminum foil, and the 20µm thick copper foil the punching operation was successful. The holes produced were free of deformation, cracks and long burrs. Figure 9 shows the holes produced by the tungsten punch.

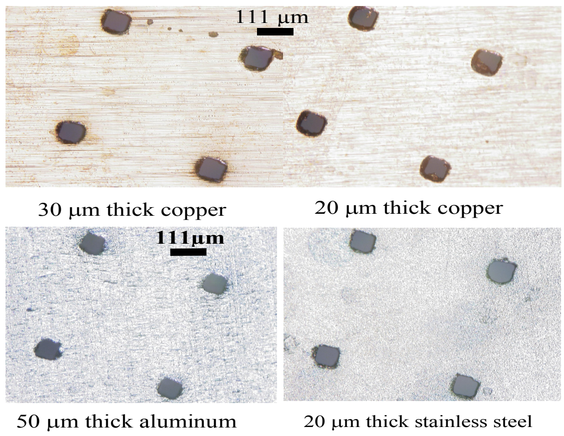
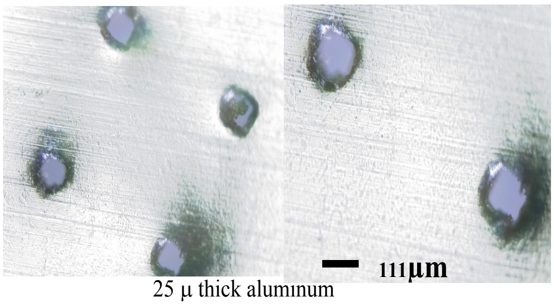


Figure 9. Micrographs of holes by tungsten punch.

The 25µm thick aluminum posed some difficulties during set up and punching. It was difficult to keep it flat on the die surface or from bending or warping. After the punching operation the holes were not clean. Burrs and other forms of deformation were visible on the sheared surfaces. This was believed to be as a result of incorrect clearance between the punch and die. Another reason was that the 25µm thick aluminum foil was too thin, and as of such movement might have occurred during the punching operation.

In addition the holes of the 20µm thick copper foil were not as clean as that of the 30µm copper foil. Small portion of the waste chips were not totally removed and some burrs could be seen on one or two of the holes. It was concluded that this was a result of using the same clearance as that used in punching the 30µm copper foil. This clearance was a little too large and resulted in the minor defects observed. This was not considered a major concern, as the necessary adjustments were made and the problem solved. A small vacuum pump was also attached to the die side of the hole to aid chip removal, as well as, to help keep the material flat on the die face. Figure 10 shows the holes produced on the 25µm thick aluminum foil.



25 µ thick aluminum

Figure 10. Micrograph of 25µm thick aluminum foil holes with too much clearance.

3. Results and Discussion

From the experiments it was concluded that different materials can be used as the punch tool, as long as they are conductive. However, there will be limitations as to the type of materials that can be punched, as in the case of the tool-steel punch. This was because of the hardness of the material. The tungsten punch was able to punch all the tested materials. After over 900 heats on the punches used for the aluminum foil, copper foil and the stainless steel foil, the punch showed no signs of cracks, wear or any other forms of deformation. Also the punched holes showed no signs of irregularities in shape or smoothness. Based on these results, tungsten has been confirmed as the best material for making the multi-point micro-punch. Although tungsten is usually a very difficult material to machine, using the processes of wire EDM negates such difficulties and makes the production of various shapes, length and sizes possible, depending on the capabilities of the WEDM machine. The effect of clearance and gold plating the punch tools were extremely important to the success and effectiveness of the punch tool and the punching operation and as such, are discussed separately below.

3.1. The Effects of Clearance

During the trial punching it was discovered that the normal practice of using 5 percentage of stock thickness per side for the clearance as a standard was not applicable. This was due to the size of the parts. Near optimum clearance was necessary to produce holes that were free from long burrs and other forms of deformations. With insufficient clearance the defect known as "secondary shear" was produced. This is when the fracture of the punch cutting edge misses the fracture of the die cutting edge. This effect was observed after punching the 25 µm aluminum foil shown in Figure 10. Although the punching was successful, secondary shearing occurred, evident in the formation of long burrs seen on the sheared surfaces of the holes. For the stainless steel, insufficient clearance resulted in "spring back". In this case the punched holes became smaller and gripped to the punch tool, often causing bending and breaking of the tool. Additional problems observed includes, increase in desired punching pressure and large stripping force which caused part distortion, extra punch wear and reduction in tool life. These defects decreased as the percentage clearance increases towards optimum clearance. In cases where the clearance was too large, extreme plastic deformation occurred [18]. Increase in burr formation and burr height and excess roll-in at the punch side of the holes were also noticed. Gripping of the punch tool to the material was also observed with excessive clearance, which was a result of tapered holes formed during the punching process.

It is therefore imperative for effective punching to obtain clearance that is near optimum, as too small or too large a clearance will result in undesirable deformations and conditions. With the correct clearance the angle of fracture permits a clean break below the cut band because the upper and lower fractures extend toward one another. As such, correct or proper clearance is one which does not cause secondary shear and result in only a minimum degree of plastic deformation [18].

The desired clearance was achieved by varying the EDM processing parameters during the machining of the die holes, depending on the material thickness and the kind of material. For the copper and aluminum foils a capacitance of 1000 pF was used and a capacitance of 2000 pF for the stainless steel foil. This provided the clearances necessary to punch quality holes in the various materials. Based on the results of the trial punching, it was concluded that a clearance of 18% to 21% is best for the 20µm thick stainless steel foil, 9% to 14% for the 30µm copper foil and 7% to 9% for the 50µm thick aluminum foil. Even with optimum clearance, burr formation can still occur, especially when punching thinner and softer materials. The small vacuum pump that was added to the punching unit help ensured continuous punching without the problem of unwanted chips. It also helped reduced burr formation and with preventing the material from sticking to the punch tool after the punching process was completed. The experiments also confirmed that clearance between punch and die also depends on the tensile strength and yield strength of the material, and on material thickness. As tensile strength, and yield strength increase the required clearance increases. In the case of material thickness, required clearance increases as thickness increases.

3.2. Effects of Gold Plating

Tungsten is one of the best and most used material for electrodes employed in the production of micro holes by micro-EDM, micro-drilling or other forms of micro-hole or micro-slot manufacturing. This is because of the low machining energy involved when compared with other processes. However, one of the major disadvantages is the low material removal rate, which translates into lengthy processing time. In other researches ultrasonic machining and vibration assisted EDM machining have been investigated and used to improve the efficiency of the machining process [1, 19].

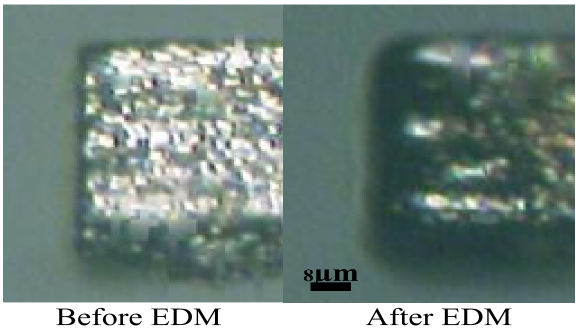


Figure 11. Gold plated punch before and after EDM process.

In this research the problem of lengthy discharge process time led to an additional disadvantage. Due to the lengthy discharge process the surface of the punch became rounded and uneven. This made punching almost impossible, as the punch tool surface must be flat and acute for effective punching. In order for punching to be possible the surface of the punch was flattened by reverse EDM, as explained earlier. Although the process of flattening the punch tool after the EDM process of the die hole resulted in successful punching the problem of lengthy processing time still remained and the process was made longer by the additional reverse EDM process. The effect of gold plating was examined based on the success in a previous research [2]. A thin gold film of 20 nanometer was added to the surfaces of the punch-points of both the tool-steel punch and the tungsten punch using the process of vapor evaporation. The process of gold plating was done by a gold plating company. The punches were then used to machine the die holes and then as the punch for the test materials, using the same parameters as before. The use of the gold plated punches resulted in a drastic reduction in the discharge processing time and the process of flattening after the EDM process of the die holes was no longer necessary because the problem of rounding of punch-points and unevenness of punch surfaces no longer existed. Figure 11 shows the surface of the punch before and after the EDM process of the die holes. In addition to the reduction in discharge processing time and punch surface roughness, the sheared surfaces of the holes produced by the gold plated punch were much cleaner. They were free from burrs and the sheared surfaces appeared to be much smoother and in general, of better quality than the holes produced with the non-gold plated punches. Figure 12 shows the holes produced using the gold plated tungsten punch.

4. Conclusion

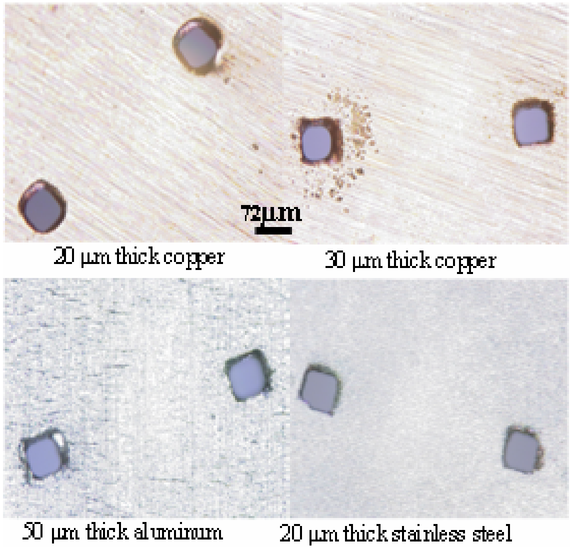


Figure 12. Micrographs of holes punched by gold plated tungsten punch.

In this paper a multi-point punch and die set was developed using the processes of EDM. The punch-points were gold plated in order to reduce the discharge processing time, surface roughness and the rounding of the punch-points during the machining of the die holes. The results obtained from the trial punching are summarized as follows:

1. Tungsten (W) is a good material for making the punch tool because it can be used effectively as the electrode for the die holes and as the punch tool for all three tested materials.
2. Remarkable reduction in the die holes discharge processing time, surface roughness of punch- points and rounding of punch surface was achieved by gold plating the punch.
3. The problem of proper punch and die alignment is eliminated with the use of the die-set.
4. The punching of various materials (copper, stainless steel and aluminum) was possible without damages to the punch cutting surfaces or changes in the dimensions of the punched holes.
5. It was demonstrated that movement of the work piece during the punching operation, flatness of the die and punch surface could affect the quality of the punched holes. Therefore, care must be taken to ensure that this movement is eliminated and flatness of both surfaces is achieved.
6. It was confirmed that if the diameter of the punch, and the material type and thickness changes, the processing condition for the EDM process of the die hole must also be changed to maintain proper clearance between the punch and die holes.
7. Achieving near optimum clearance between punch and die is essential to successful punching. This is possible by controlling the processing parameters during the EDM process of the die holes.

The results obtained so far by the micro punching system using tungsten and other materials for making the multi-point micro-punch, are evidence that this system can be successfully applied to various manufacturing industries to mass produce micro-holes.

References

[1] T. G. Endo, T. Tsujimoto, K. Mitsui, "Study of vibration-assisted micro-EDM-The effect of vibration on machining time and stability of discharge". Precision Engineering, Vol. 32, No. 4, 2008, 269-277.

[2] T. Mori, "Development of ultra-fine piercing by SiC fiber punch". Transaction of ASME Journal of Manufacturing Science and Engineering, Vol. 126, 2004, 659-665.

[3] M. Fujino, M. Yamamoto, T. Masuzawa, "Micro-punching system as an application of WEDG". Institute of Industrial Science, University, Tokyo, SEISAN-KENKYU, Vol. 39, 1987, 277-280 (in Japanese).

[4] G. Chern, S. Wang, "Punching of noncircular micro-holes and development of micro-forming". Precision Engineering, Vol. 3, 2007, 210-217.

[5] Schonberger RJ. World class manufacturing: The Next Decade. New York: The Free Press; 1996.

[6] Martellucci S, Chester AN, Scheggi AM. Laser applications for mechanical industry, NATO ASI Series. Boston and London: Kluwer Academic; 1993.

[7] T. Masuzawa, HK. Tonshoff, "Three-dimensional micromachining by machine tools". Ann CIRP 46. 1997, 621-628.

[8] M. Yamazaki, T. Suzuki, N. Mori, M. Kunieda, "EDM of micro-rods by self-drilled holes". Journal of Materials Processing Technology, Vol. 149, 2004, 134-138.

[9] H. Lim, Y. Lim, S. Kim, "Fabrication of tungsten micro-punch for micro-nozzles". Review of Scientific Instruments, Vol. 72, 2001, Number 8.

[10] P.J. Bryant, H.S. Kim, Y.C. Zheng, R. Yang, "Technique for shaping scanning tunneling microscope tips". Review of Scientific Instrument, Vol. 58, 1987, 1115.

[11] M. Fotino, "Tip sharpening by normal and reverse electrochemical". Review of Scientific Instrument, Vol. 64, 1993, 159.

[12] B. Joo, S. Rhim, S. Oh, "Micro-hole fabrication by mechanical punching process". Journal of Material Processing Technology, Vol. 170, 2005, 593-601.

[13] F. Vollertsen, Z. Hu, H. S. Niehoff, C. Theiler, "State of the art in micro forming and investigations into micro deep drawing". Journal of Materials Processing Technology, Vol. 151, 2004, 70-79.

[14] K. Hanada, L. Zhang, T. Sano, "Fabrication of diamond dies for micro forming". Diamond Related Materials, Vol. 12, 2003, 757-761.

[15] Jameson EC. Electrical discharge machining. Dearborn, Michigan: Society of Manufacturing Engineers; 2001.

[16] Wilson WW, Harvey PD, Gump Jr CB. Die design handbook. 2nd ed. New York: McGraw-Hill Book Company; 1965.

[17] N. Tarkany, "Improving perforated die performance: The effects of stress, clearance, material". Stamping Journal, 2003. Visit Also: http://www.thefabricator.com/ToolandDie/ToolandDie_Article.cfm?ID=549.

[18] Eary DF, Reed EA. Techniques of pressworking sheet metal. Englewood Cliffs New Jersey: Prentice-Hall, INC; 1958, 10-33.

[19] G. Chern, Y. Chaung, "Study on vibration-EDM and mass punching of micro-holes". Journal of Materials Processing Technology, Vol. 180, 2006, 151-160.