Optimum Shape Design of Cemented Carbide Micro-Drill in Consideration of Productivity

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Abstract: Recently reduction of industrial products in size and weight has been increased by application of micro-drills in gadgets of high precision and a great interest of a micro-drilling has been raised. Due to the lack of tool stiffness and the chip packing, the micro-drilling requires not only the robust tool structure which has not affected by vibration but also effective drilling methods designed to prevent tool fracture from cutting troubles.

This paper presents an optimum design shape of a 0.15 mm micro-drill associated with a new manufacturing process to improve the production rate and to lengthen the tool life and suggestions on the micro-drilling characteristic properties associated with the tool life and workpiece quality.

Keywords: Keywords: Micro-drill, Optimum design, Productivity, Cemented carbides material, Tool life, Workpiece quality, FEM.

1. INTRODUCTION

Drill processing is the most basic processing method among machine processing methods and it is gradually change to high-speed process for the productivity improvement. Also, the drill process required a miniaturization and deep hole drilling associated with the trend of high technology, varieties, and miniaturization of electronic products. Specially, recent development of high technology medical system or advanced material of small size element requires a nano-micrometer size of drill process, and development of micro-drill for the element process and evaluation of the process of the element could be prominent facing project.

In the nation, the importance of the micro process technology recognized for a high technology medical system, a miniaturization of penetration hole with the improvement of the VLSI which is required on the computer circuit board, a development of new resin, a high density multi-layer wiring of circuit board, and a development of miniature part with high technology accumulation.

Currently, even though a micro-drill which of tenacity increased by particulate of hard metal developed, it faced a lot of problem for the high speed cutting (1). Also, several drills such as a composite tool which was TiC and TaC annexed drill tool for heat resisting, a composite drill with sintered diamond attached at the tip of hard metal drill, and a fine drill with diamond coated at the drill tip, etc. were developed. The drill employed the diamond has more ten to hundred times tool life respect to the hard metal drill and allowed high accurate process due to good cutting capability and anti-abrasion based on the hardness and heat conductivity of the diamond but it has difficulty of tool manufacturing (2).

This research studied basic design factor for development of micro-drill less than 0.15 mm diameter with hard metal material and carried out optimum shape design based on results of above study. The finite element method was applied for the stiffness analysis of the drill and simulation of modeling with three dimensions used for the shape design of each element of and overall drill. The productivity such as tool life and process quality (e.g., roundness and straightness) was considered for the optimum shape design as high speed tool. This research also established a basic process technique of the micro-drill based on results of the performance test of manufactured drill by this research.

2. SHAPE DESIGN OF THE MICRO-DRILL FOR BETTER PRODUCTIVITY

2.1 Affecting Factors for Optimum Design

This study carried out the optimum design of the less than 0.15 mm micro-drill for better productivity. The cemented carbides is an alloy which Rockwell hardness (HRC) is 70-80 made by sintered of carbide powder. Generally used hard metal tools are sintered metal of Co and W powders based on carbide tungsten. The selection of the cemented carbides tool for the micro-drill considered the physical characteristics such as hardness, tension, toughness, particle size, and density. The drill stiffness and performance was greatly affected by the particle size in the case of the same material. Figure 1 shows the major factors in design of the micro-drill. In figure 1, A and B is the length of cutting edge and the difference of A and B length affects the gap, overlap, and location of hole. C is the web thickness affects the stiffness of the drill. D and E is the width of the cutting edge and the difference of these two affects the stiffness and induces vibration when it revolute with high speed. F is the lay back which affects the melting of the chip. G is the hook which affects the stiffness somewhat. H is the taper which affects the chipping and stiffness. I is the flare which affects the G and stiffness. J is the web offset which affects the centering of the process directly. Also, the cemented carbides micro-drill used be difficult to process the steel or hardened and brittle material, but currently it was possible to use it by complementing the cemented carbide drill.

When design the drill, high stiffness and high accuracy of the processing machine was required with the high revolution, and lower the slope by considering the breaking, and consideration of the possibility of breaking or chipping was required. Thus, this research selected the size of the particle as fine powder less than 0.6 ㎛ for the micro-drill tool which was predominant on hardness, tension, toughness, particle size, and density for cemented carbides micro-drill.

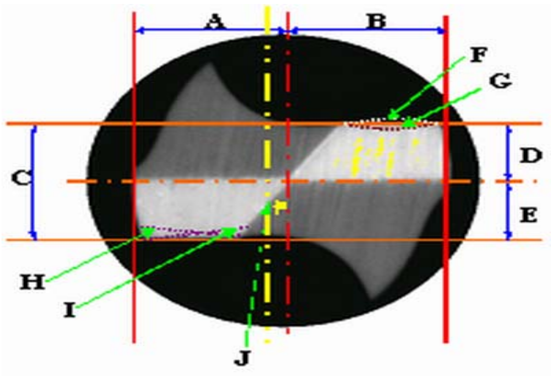

Fig.1 Influence components of micro-drill

2.2 Optimum Design of Stiffness Based on FEM Analysis

The stiffness analysis of cemented carbide of 0.15 mm diameter of micro-drill was carried out using FEM with solid model of three-dimensional shape for the optimum design for better productivity. The analysis of the mechanical stiffness was for restraint the broken of the micro-drill during the process and maximize the tool life. The major component of WC and Co of cemented carbide was selected as sample. The coefficient of the elasticity and Poisson ratio of the sample was 40,000 kgf/mm2 and 0.31, respectively. The boundary condition for the analysis was equally spaced unit load on the axial direction of the cross section of the drill edge. The drill tip was divided equally into three parts for the analysis as shown in figure 2.

Figure 3 was result of the analysis which shows the deformation of the drill edge. As shown in figure 3, the deformation due to load was greatest at the center of the drill edge during process of the micro-drill and it indicated that the load was greatest at the center. Meanwhile, the distribution of the shear stress as shown in figure 4, the maximum stress occurred at the inner end of the drill tip (red color portion). This indicated that the stiffness of the micro-drill at this point was the lowest. The stiffness of the drill was low at the start point of the taper which was boundary of the shank and body part. This indicated that emphasis required at the drill edge and the start point of the taper when design the 0.15 mm micro-drill.

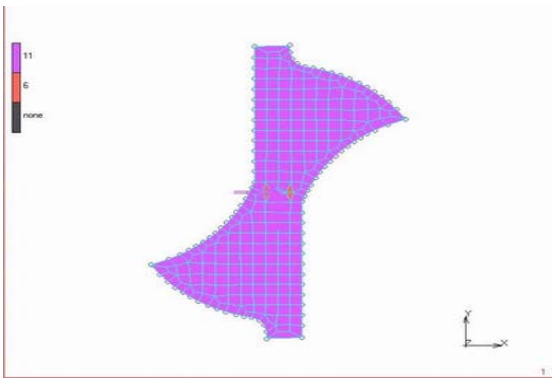

Fig.2 Solid model for analysis of microdrill by FEM

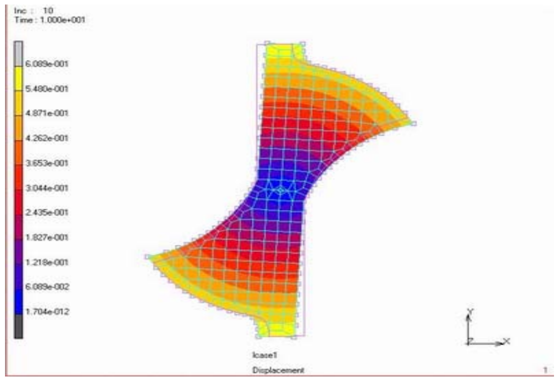

Fig.3 Result of FEM analysis of deformation

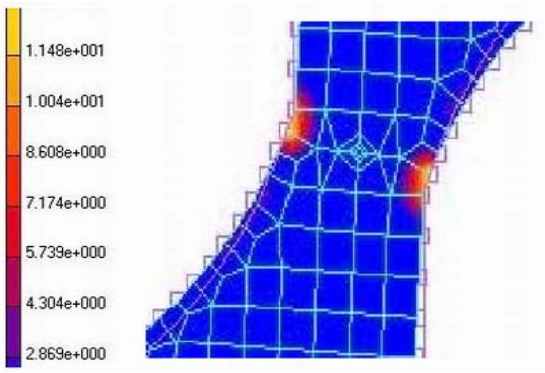

Fig.4 Result of FEM analysis of shear stress

3. SHAPE DESIGN OF THE MICRO-DRILL

The total shape design of the cemented carbide micro-drill for better productivity required a consideration of applicability to current attachment system of processing machine (3, 4). Affecting factors for processing capability and tool life of the micro-drill were chisel angle, point angle, helix angle, web thickness, margin width, flute width, and tinning. Also, overall length, shank diameter, body length, flute length, and undercut of the micro-drill affected the processing capability and tool life. Among those, helix angle, flute length, point angle, web thickness and undercut were important factors affecting the tool life and productivity of the micro-drill (5).

This research carried out shape design of the body, cross section, and point part of the micro-drill using three-dimensional modeling for effective design. The design procedure was as follow. The design was first carried out at the virtual space and shape verification was carried out using three-dimensional simulation. Next, the correspondence of the shape of the micro-drill made by computer program was inspected base on the original design purpose. The tool shape of the micro-drill during manufacturing process was inspected in parallel.

The result of the test of the 0.15 mm micro-drill manufactured based on original design indicated that allowed margin at the drill point speeded up the wear of the drill point. The tinning part of the micro-drill designed as X-type shape. The reason to select X-type was since S-type and N-type was actually difficult to manufacture because the drill diameter was very small in micro-drill and W-type leaded abrasion easily at the drill point due to weak stiffness. The drill points slope angle = 12-15 , shear angle = 120-125 , and helix angle = 30-35 was selected. The slope and shear angle was selected greater than general drill to maintain the enough stiffness relative to the very small drill point of the micro-drill. The selection of the helix angle = 30-35 was to maximize the cutting capability of the drill.

4. OPTIMUM DESIGN OF THE EACH FACTOR OF THE MICRO-DRILL

4.1 Optimum Design of the Helix Angle

The helix angle of the drill role the slope angle of the circumference of the drill and the resistance decreased due to improvement of the cutting capability as the helix angle increased but the discharge of the chip was weakened (5). Also, it caused the vibration due to the depreciation of the stiffness of the micro-drill. Thus, the degree of the helix angle needed to be change relative to workpiece material to maximize the productivity and tool life of the micro-drill.

Figure 5 shows the tool life and roundness of a workpiece respect to the helix angle. The tool life increased as the helix angle increased up to 35 then decreased. Meanwhile, the roundness error was smallest at the helix angle in the range of 25 - 30 . Thus, proper helix angle was in the range of 25-30 but it needed to be changed respect to the workpiece type for the better productivity. That is, the tool life decreased with the large helix angle of the micro-drill for the mild workpiece process due to vibration and chipping but the tool life of the micro-drill extended due to less heat generation relative to the small deformation of the chip.

Also, the large helix angle recommended for the aluminum process which emphasized the cutting capability with less cutting resistance and stainless steel and heat-resistant material process which induced the work hardening during process. The low chip discharge capability of the micro-drill weaken the hole processing status and the tool life of the micro-drill decreased if the chip discharge capability decreased due to higher working load.

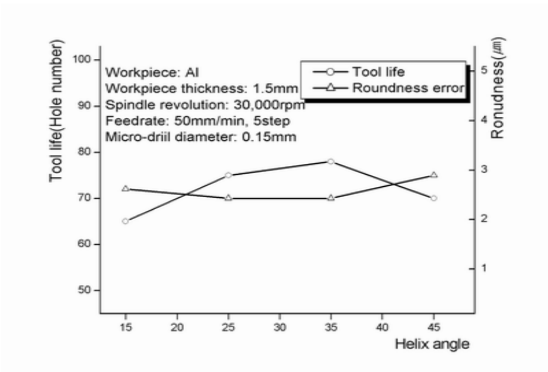

Fig.5 Tool life and roundness error variation according to helix angle

4.2 Design of the Flute Length

The flute constituted the slope angle of the cutting edge by the helix angle and point angle and determined the performance of the micro-drill. Also, the flute was pathway of the chip discharge and inflow pathway of the cutting oil. If the length of the flute was too long, the centering was poor at the initial stage of the process due to the decreased stiffness of the micro-drill and the hole diameter was widen due to poor accuracy of the hole.

The stiffness of the micro-drill decreased as the flute length increased. But, the flute length could not be decreased to increase the stiffness of the micro-drill therefore the flute length could be designed to maximize the stiffness respect to the thickness of the workpiece. Figure 6 shows the tool life of the micro-drill respect to the flute length. The tool life of the micro-drill decreased as the flute length increased due to weaken the stiffness of the micro-drill. Figure 7 shows that the accuracy of the centering of the micro-drill decreased as the flute length increased. Figure 8 shows the straightness and roundness respect to the length of the flute. As shown in figure 8, the straightness and roundness affected a lot by the length of the flute. That is, as the length of the flute increased, the roundness getting worse due to the poor centering of the initial stage of the process and the straightness getting worse during the process due to vibration induced by the weakening of the stiffness.

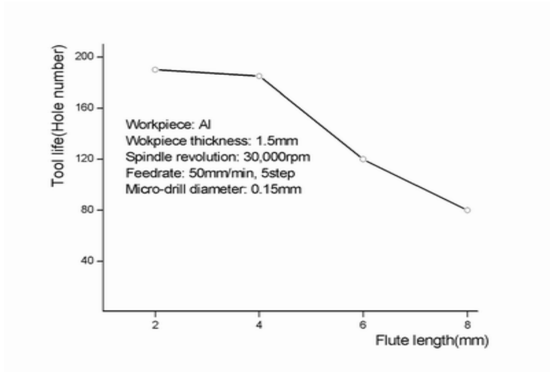

Fig.6 Relationship between tool life and flute length

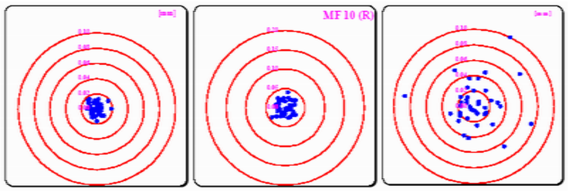

Fig.7 Centering accuracy according to flute length of 2mm(left), 4mm(center), 8mm(right)

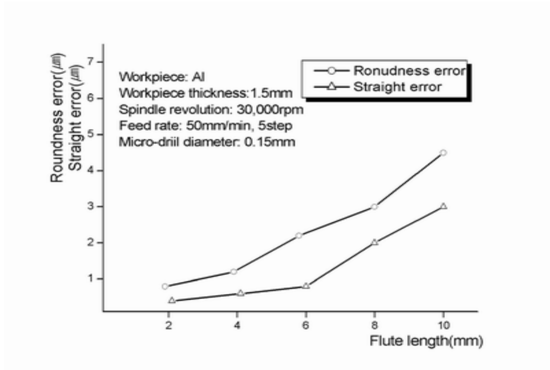

Fig.8 Roundness and straightness error variation according to flute length

4.3 Point Angle and Cutting Resistance Considered Design

The point angle affected the cutting performance and it was generally recommended as 118 - 140 . Typically, however, the point angle of 118 was recommended as standard. If the point angle was too small, the cutting edge length increased and the chip shape was thinned consequently the cutting resistance increased per unit.

Figure 9 shows the trust and torque respect to the point angle. As shown in figure 9, as the point angle decreased, the trust decreased, the torque increased, and the occurrence of the burr increased after processing. Reversely, as the point angle increased, the trust increased but the torque decreased and the diameter a hole increased after processing, however, the occurrence of the burr restrained and the tool life increased. But, the cutting capability became worse at over the limit of the point angle and increased the processing load consequently induced bad processing quality.

Thus, this research selected the point angle of 130 of the micro drill of less than 0.15 mm diameter and obtained generally reasonable results on cutting capability and processing quality.

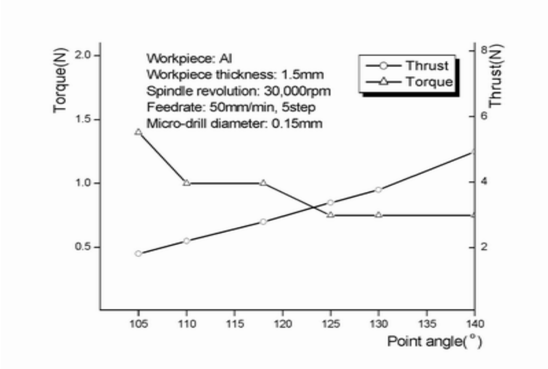

Fig.9 Thrust and torque variation according to point angle

4.4Design of Web Thickness and Drill Stiffness Consideration

The web part of the micro-drill formed the axial part of the micro-drill and analyzed on emphasis of design of the cutting capability and the stiffness. The web thickness was a thickness of the center part of the micro-drill and formed the axial part of the micro-drill and the stiffness of the micro-drill was determined at this part. Generally, the web thickness was 11-20% of the diameter of the micro-drill and the web thickness was selected as 28-33% of the diameter of the micro-drill in general for metal processing. Depend on deep hole processing, the web thickness was considered as up to 55% of the diameter of the micro-drill.

This research carried out the preliminary study for determination of limiting condition of the optimum web thickness for to maximize the stiffness and cutting capability of the micro-drill for metal processing. As shown in figure 10, the stiffness of the micro-drill sharply increased as the web thickness increased. The cutting capability, however, sharply reversed after a limiting value of the web thickness. Thus, this research selected the web thickness as 30-40% of the diameter of less than 0.15 mm micro-drill to maximize the cutting capability and to give satisfaction on the stiffness of the micro-drill.

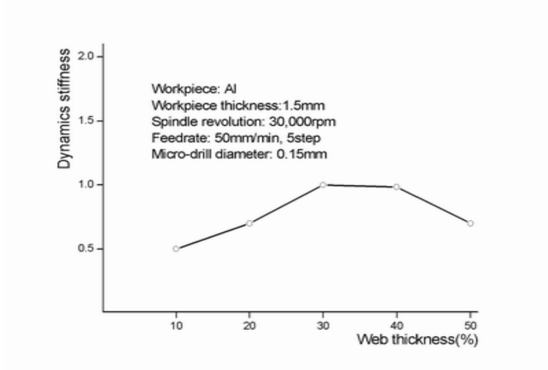

Fig.10 Relationship between web thickness and dynamic stiffness for micro-drill

4.5 Design of the Untercut on Friction Force Consideration

The diameter of the micro-drill designed such that the diameter decreased as move from the point to the shank part in order to minimize the friction of the circumference of the micro-drill against workpiece. That is, to eliminate the friction with workpiece at the margin part, the outer diameter was designed as 0.02 0.08 mm less per 100 mm of diameter of a drill (2-8%). But, if the undercut was over a limit, the roundness and straightness of a hole decreased due to weakening of the dynamic stiffness during a process. Thus, this research designed the undercut as 0.04 0.05 mm (4-5%) per 100 mm based on the discussions above two factors and results of test showed that the friction force was minimized.

4.6 Design in Consideration of Roundness Respect to Processing Time

Figure 11 shows the roundness respect to the processing time of the micro-drill and it shows results of the roundness of a hole in SEM photograph after one, 10, 100, and 127 processing times. As results shows, the roundness error increased as the processing time increased. In general, the roundness error of a hole at the first was about 2㎛ and at 100th was about 5㎛ and 2.5 times deteriorated. The roundness error was 20㎛ at 127th hole and seriously deteriorated.

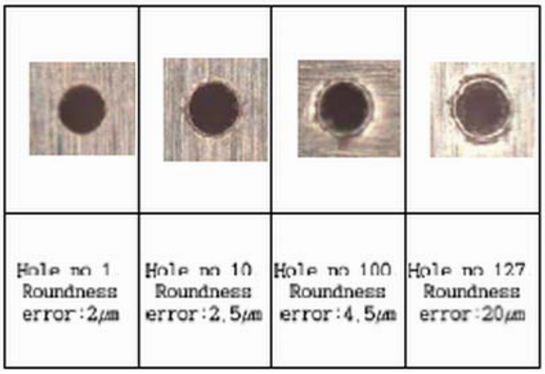

Fig.11 Roundness error according to number of micro-hole

5. OVERALL SAHPE DESIGN

The shape design of the cemented carbide micro-drill considered the chuck of the current processing machine and appropriateness of the collet specification and designed to maximize the tool life based on the toughness and the stiffness. Figure 12 shows the result of the overall shape design of the micro-drill with the shank length of 3.170 mm, the overall shape length of 38.1 mm, the flute length of 1.0-6.0 mm, the body length of 25.4 mm, the point angle of 130 , and the taper angle of 30 and other elements of the micro-drill was designed as discussed above in section 4.1-4.6.

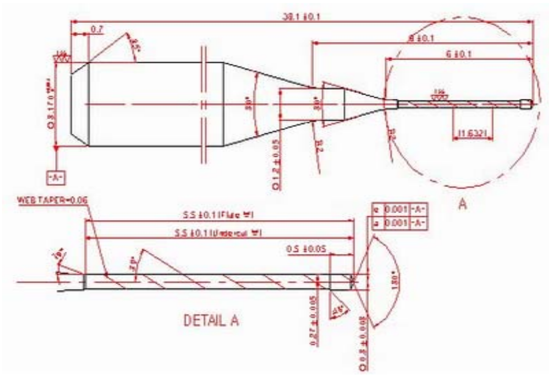

Fig.12 Design of overall shape for micro-drill

6. RESULTS

This research suggested a processing technique for development of less than 0.15 mm in diameter of the cemented carbide micro-drill based on the optimum shape design and performance evaluation such as the shape design of each part of the micro-drill with different tool materials, the overall shape design for better productivity, the stiffness analysis of the high speed drill for tool life, and the roundness and straightness analysis of workpiece. Following is summarized results obtained from this research.

(1) Overall shape, body length, flute length, and taper angle was determined for the design of the stiffness of the less than 0.15 mm in diameter of the micro-drill for better productivity based on the mechanical stiffness analysis using finite element method (FEM) and of the shear stress analysis.

(2) Design of in each factor, such as determination of the helix angle considered the easiness of the chip discharge, tool life, and roundness, determination of the flute length considered the relationship between the helix angle and the point angle and centering, determination of the point angle considered the cutting resistance, determination of the web thickness considered the drill stiffness, and the design of the undercut considered the friction force during processing. Also, each factor was determined based on the roundness respect to the processing time to maximize the workpiece quality.

(3) The determination of the optimum shape of the micro-drill considering the FEM and the drill tool life to maximize the productivity was resulted as the shank length of 3.170 mm, overall shape length of 38.1 mm, flute length of 1.0-6.0 mm, body length of 25.4 mm, point angle of 130 , and taper angle of 30 . Also, designed the optimum shape of the micro-drill using results of preliminary test of the micro-drill manufactured based on above design.

(4) Established the basic processing technique of the micro-drill through the performance evaluation of the micro-drill manufactured based on the design.