Manufacturing Process of Micro-drill

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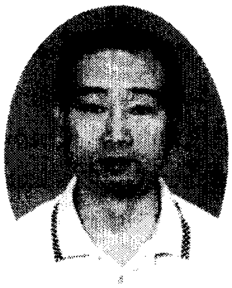

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1. Preface

Drilling operation is one of the most basic manufacturing methods among the machine tool manufacturing and it is getting more important for improving the productivities associated with micro-drill manufacturing. In order to keep up with the trend of high performance, miniaturization of electronic products, an increased need for high precision drilling works are required. Particularly the need of nano-micrometer detailed drilling works are rising. Due to the rapid development of high-technology medical equipments and new micro-element particles. Therefore there should be new studies and developments of micro-scaled drills and their new elements.

In Korea to be sure, the importance of micro-machining technology is rising due to hole-miniaturization, new material developments, high density of circuits, multi-layers circuits and high integration for improvement of VLSI integration on high-technology medical equipments and computer circuits[1]. In advanced industrialized countries such as U.S.A and Japan, micro drill machine equipped with high-frequency air spindle, has been already practiced for the use of micro manufacturing and reported to make possibly hole drilling work. These manufacturing process can not be seen with naked eyes, so drilling process monitoring has been automated through torque detection or acoustic emission sensor.

Nowadays, we see empowered-endurance drills by making corpuscle with cast sintered alloy, but producing problems with high speed cutters. Developments of multi-purpose drilling tools with consideration on heat-resistant adding TiC, TaC are on the way. In addition, there has been drills developments such as cast sintered alloy multi-purpose drills with adding diamond to the top of the drills and microscopic drills adding diamond to the top of them. When using diamonds, the degree of hardness, thermal conductivity and abrasion resistance are to be improved by ten times up to hundreds times of tool life expectancy and high precision ability. However the major problem is that it is extremely hard to manufacture such drilling tools. Therefore optimum design of micro-drill shape and manufacturing process technology are urgently required.

This study therefore focuses on the technology on material selection of micro-drill tool, manufacturing method for mass production and also a large quantity production for scale of 30㎛ or under micro-drill developments, and evaluation of micro-drilling operations.

2. Purpose and Study Background of Micro-Drills Development

2.1 Purpose and Study Background of Micro-Drills Development

Micro-drill manufacturing technology will be the frontier engineering in 21st century so that advanced nations are taking this important and funding into this with passion. By having this advanced and high value-added technology, we can produce high-technology products. Only 4 countries have this micro-drill manufacturing technology (0.04mm; 40/1,000mm, compared to human hair size of 100/1,000mm), importantly the 4 countries are hesitating to transfer this technology to other countries because this technology is a future coming gold technology. Due to a diameter of ten~hundreds micrometer, this micro-drill for use of drilling needs high speed spindle to gain consistent cutting speed.

In Korea, there has been a big interest in miniature drilling driven by increased demand in printing company, IC purpose mikes from 1970th. High-tech drilling development started to minimize burring sound from mikes in the late 80th. From the late 80th, miniature drills(under 3mm) development started to cope with the large quantity production of printer circuit mould, since then automatic drilling works started with introduction of CNC machines. The more microscopic the micro-drilling, the more precious manufacturing and design of the drill needed. Today it is possible to manufacture the drills scaled of 0.3~1mm.

Today within the domestic industries, micro-machining is getting important to cope with the trend of high density of circuit board, new material developments that needed for high-tech medical equipments and computer circuit board. This situation has produced an urgent need of credible data collection for micro-drilling and manufacturing ability.

2.2 Domestic and the World Trend of Studies on Micro-drills

U.S.A and Japan are now successfully utilizing drilling machines that attached with air spindle used for microscopic drilling works. That means the drills can conduct hole drilling works scaled 50㎛ up to tens of micrometer. These works can not be detected effectively by naked eyes so that torque detection or sound detection are being used to have effective monitoring systems for drilling works.

2.3 Utility Fields of Micro-drills

Micro-drilling are mainly used to produce cameras, audio machines, video players, computers, high-tech medical equipments and monitoring systems. Importantly, micro-drills are being utilized to perform works of hole-drilling scaled diameter 0.1mm~0.5mm on multi-layers circuit board of printers. And the numbers of the holes are thousands up to ten thousands on each board. Because fuel injection, nozzle holes, optical fibers, microscopic nozzles, space engineering, medical equipments and measurement gauges are getting microscopic, there are many studies are on the way to manufacture micro scaled drills to keep up with the new needs of complicate and compounded shape and moulds of the above the products.

A study shows, the shape and the material of micro-drills have a big influence on the effectiveness of drilling and the final products that manufactured by the drills. Drills that equipped with durability, heat-resistant and economy are urgently required to be created. The materials used to make micro-drills are high-speed steels and sintered cemented-carbide alloys, while the former is weak by durability and the latter is weak by abrasion. In order to minimize the weakness of the high-speed steels, a method of making sintered cemented-carbide alloys by corpuscles but this still has problems with high-speed cuttings.

There are many tries to make drills, for examples, drills made of TaC compound materials to give heat-resistant, multi-purpose drills made of ultra-light compound materials attached with diamond to the top and micro-drills coated with diamond to the top. A study shows, solidity, heat conduction can be improved and these can eventually improve cutting ability and abrasion proof. These all not create far more tool life expectancy up to hundreds times but also high precision works. However it is extremely hard to make such drills so far. Therefore optimum manufacturing processes and manufacturing plans are urgently required for micro-scaled drills making.

Korea today imports 100% of micro-drills and their parts and the import is seen as dramatic increase in the future. The current domestic market value of micro-drills is KRW 120 billions while their parts and materials consist of KRW 1.6 trillions and the world market value is estimated about $90~100 billions.

3. Micro-drill Shape Designing

This study aims at making micro-drills scaled below 100㎛. The same scaled drills on the current market are being sold at about KRW 15,000 and they are all imported from Japan. The average life expectancy is from 3 to 6 holes per tool and manufacturing costs are very high.

The manufacturing processes recommended by this study is different from others. As seen on Fig. 1, it has total 9 steps consisting of grooving & cutting, grooving, compression & beading, twisting, cutting, cross rolling, heat treatment, cylinder grinding, edge grinding, measuring, and testing on the high-speed steel. The materials meeting the requirement for making such drills are high-speed steels and carbon steels.

And also Fig. 2 indicates the manufacturing processes for the sintered cemented-carbide alloys, it has total 10 steps consisting of centerless grinding, profile grinding, point angle grinding, taper grinding, grooved-coating, grooved-etching, cleansing, and testing on the sintered cemented-carbide alloys.

Such manufacturing mechanics will be able to produce massive products by using plasticity of metals, and this will be successfully reducing costs of manufactures and have competitive price against drills imported from Japan and other countries. However, the method of manufacturing drills requires credible data by constant studies on the weaknesses of the method. Particularly the parts of shank, flute and the top require studies on heat treatment and efficiency of drilling works such as hardness, life expectancy and toughness. Importantly more effective heat treatment is needed to minimize the danger of brittle condition driven by difference of heat treatment time.

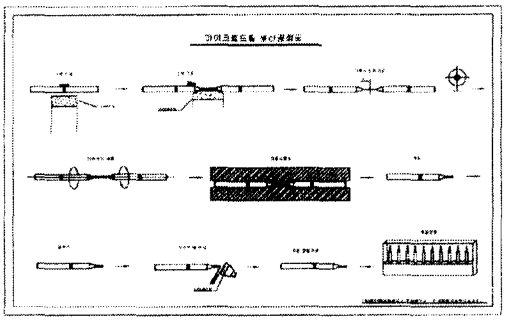


Fig.1 The manufacturing processes for the material of high-speed steel

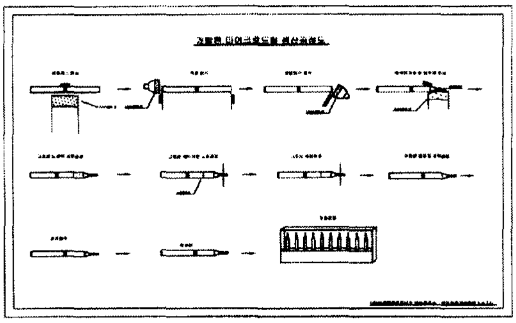


Fig. 2 Manufacturing processes for the material of sintered cemented-carbide alloys

3.1 Determination of Micro-drill Shape

Fig. 3 shows each name of the top and part of the drill. With normal drills, manufacturing works are highly influenced by chisel edge angle, shape of margin and shape of thinning, but with micro-drills processing it is not necessary to make the margin near the vertical hem and this will only encourage abrasion, a study shows. In case of micro-drills, it is designed X-type thinning shape. The reason of that is micro-drills need very small drill tips.

Therefore, S-type and N-type are not easy to make and W-type is weak by abrasion with less hardness. Fig. 4 shows the thinning shape which works on contact point between the process of drilling and structure when micro drilling work. The shape of thinning on fleet of drill have an important effect on the tool life span and cutting shape of structure. For the fleet part of drill, the rake angle is set with $\alpha=12\sim15^\circ$, shear angle $\beta=120\sim125^\circ$, twisting angle $\gamma=30\sim35$, which are wider than the angle of normal drill. The reason is to maintain a sufficient hardness on small fleet and twisting angle $\gamma=30\sim35^\circ$ is to make the greatest maximum cutting abilities. Also, the length of twisting angle is set on less than 3.5 times of that of flute part.

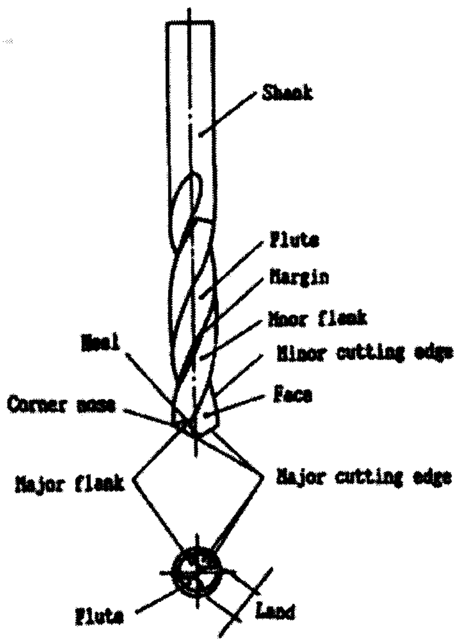


Fig. 3 Shape of micro-drill

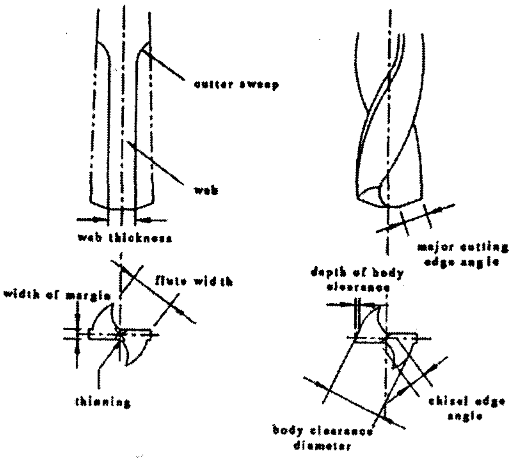


Fig. 4 Characteristic of tinning shape

3.2 Harness of High-speed Micro-drill

The shank and flute parts have an crucial effect on the tool life span of drill due to a small drill angle. Therefore, in many cases the tool life span of micro drill depends on the cutting edge of shank and flute part, unlikely abrasion on the fleet of normal drill.

Table 1 shows the experiment of cutting-process with 80㎛ and 300㎛ micro-drill. This result shows that the cutting on shank and flute part is affected by the cutting edge and angle between the fleet of drill and structure. If the edge angle between the fleet of drill and structure is φ, normally the result should be $\varphi = 90^\circ$. But the angle from the result of this experiment shows 86o$< \varphi \leq 90^\circ$ affecting by the sliding action.

Therefore, Table 2 shows the relationship between micro-drill tool life and edge angle φ. Based on the result, the larger contact angle will, the longer life span will be maintained, the smaller contact angle, the tool life is shortened. So this shows the tool life is affected by not only the hardness of drill but also the contact angle φ between the drill fleet and the structure. Also, to reinforce the cutting abilities and preciseness, 34° taper at boundary between flute part

Table 1 The life span of micro-drill

[redacted]		
1	34sec	3min 42sec
2	1min 40sec	4min 40sec
3	28sec	5min 23sec
4	1min 25sec	3min 29sec
5	48sec	5min ove
6	39sec	4min 32sec
7	53sec	4min 23sec
8	1min 3sec	3min 18sec
9	53sec	4min 33sec
10	46sec	3min 25sec

Table 2 A Tool life by edge angle φ

[redacted]		
86°	19sec	23sec
88°	26sec	33sec
90°	1min 25sec	1min 6sec

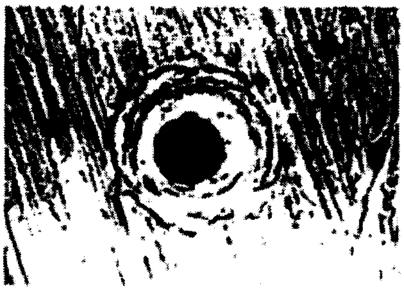
and shank part will be very important to prevent the excessive stress in case of rotating.

3.3 The Tolerance Level against Abrasion of Micro-drill

The metal microscope, SEM or laser, can be used to measure tool life by affecting the different level of abrasion on the fleet part of drill. Fig. 5 shows the pictures of abrasion shape from laser microscope. But the most effective way of measuring the tool life of micro-drill level is to predict the different type of signal after obtaining machining load sensor in case of manufacturing, and finally this will be used to save the expense of high-priced drill. Currently based on the experiment results on Fig. 8, the signal by cutting is extremely distinctive, however a deeper experiment on drill abrasion will be required to measure an accurate boundary to predict the tool life as well as a study will be needed to know the possibility to measure the tool life span of drill by abrasion.

3.4 The Shape of Crack and Direction on the Fleet of Drill

The shape of crack can be seen through laser



(a) Drill Diameter : 0.05 mm
(600rpm, 2 mm/min, Brass(t 0.3))

(b) Drill Diameter : 0.1 mm
(3000rpm, 4mm/min, Stainless(t 0.5))

Fig. 5 Abrasion of micro-drill

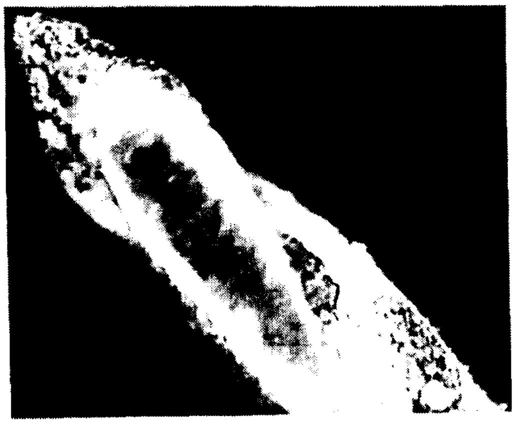


Fig. 6 Plow phenomenon on micro-holes

microscope in case of micro drilling. From this study, the shape of crack on the fleet of drill was tried to analyze, it was difficult to distinguish the precisive shape of crack due to lots of unclear parts appeared.

But based on many cases and experiments, Fig.5 Abrasion of micro-drill unlike normal drill, the bigger crack is not main factor to shorten tool life. The reason is that normally the life span itself is shorter than the time to be spent on making bigger crack.

Therefore, it will be more practical to show the relationship between the cutting abilities and abrasion rather than discovering the main factor affecting the tool life through examining the shape of crack and direction. Fig.6 shows the surface of structure in case manufacturing with 50μm and 100μm drill and both surfaces shows plow phenomenon with cutting signal. Also in case cutting, the signal is shown rapidly rising.

4. Cutting Ability and Working Loads of Micro-drill

Cutting power when drilling is too small to signal, therefore it is very important to select proper sensor to detect it. In order to monitor and detect the power signal, very sensitive sensors which are too expensive to be utilized, are needed. Another reason is tool shank of pivot type is too small. By this study, it is possible to monitor the cutting power by attaching strain gauge(tool dynamo-meter) on the surface of the

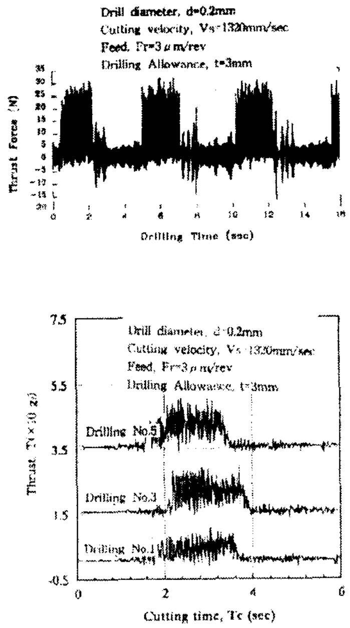


Fig. 7 Measuring signal for evaluation of drilling micro drill

objective being drilled as seen on Fig. 7. By transferring, helped by Transducer and A/D Converter, the main power signal, which is signalized and connected to a computer, we can compare and analyse the signals from drilling. This study proves that each different conditions of drill works has their own waves and unique signals.

Also the interference of chips is one of the main reason of reducing the tool life expectancy of drills when drilling. This study shows that cutting speed is the major factor effecting the tool life expectancy. In any cases, the interference of chips can be eliminated if the depth of cut is not more than 300μm and nozzle for use of air installed.

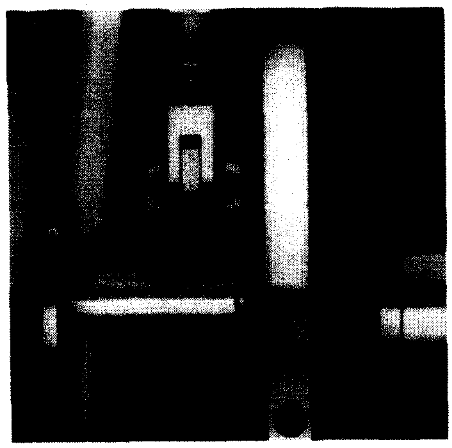


Fig. 8 The manufacturing process for micro-drill on the body

Fig. 9 The manufacturing process for micro-drill on flute

Shown on Fig. 8 and Fig. 9 show new micro-drill scaled diameter of 40/1000 mm made by new process mechanics. And also Fig. 10 indicates manufacturing products on the micro-hole drilling.

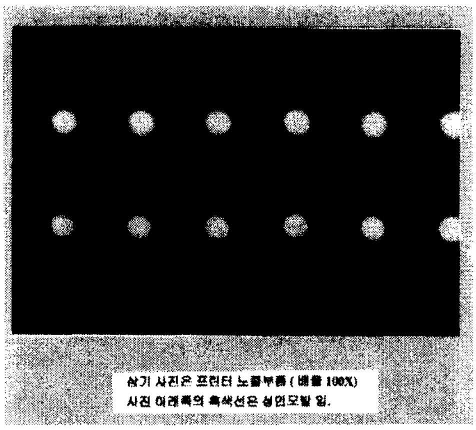


Fig. 10 Micro-drilling results on the 80㎛ holes

5. Conclusions

The conclusion of the study on development of micro-drill on the material of high-speed steel and sintered cemented-carbide alloys is as follows.

(1) Introducing a new method of manufacturing micro-drills which are high value-added and mass-production on the micro-drill.
(2) Determination and design of micro-drill shape for maximizing its life expectancy.
(3) Introduction of taper angle on shank part to improve the hardness of micro-drill.
(4) Proposal of drilling process to maximize the life expectancy of micro-drills.

Reference

(1) Peter Muller, "Flexible Usage of Micro-drill," European Production Engineering 16, pp.79~81, 1992
(2) M.S. Choi, "Effect of Geometrical Similarity betwwen Twist Drill on the Shape of Chip Produced," Journal of Korean Society of Machine Tool Engineers, Vol.9, No.6, pp.118~125, 2000