Development of Micro Drill Bit for Drilling Environment-Friendly PCBs

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Abstract

Currently environment-friendly PCBs (including lead-free assembly compatible PCB and halogen-free PCB) become popular in PCB industry to meet the requirements of environmental protection. Correspondingly, as a fundamental manufacturing process in PCB fabrication, mechanical drilling has to be innovated. A new type of drill bit is developed to provide solutions for drilling environment-friendly PCBs.

Worldwide PCB and micro drill bit manufacturing industry are briefly reviewed first. Challenges of drilling environment-friendly PCBs are described and the objective of this study is covered. Then key design points including helix angle design, primary face angle design and helix groove shape optimization are presented. The influential mechanism of drill bit key parameters on its rigidity, strength, debris evacuation capability is investigated. Helix angle, helix groove shapes and primary face angle are optimized to ensure sufficient cutting edge strength and excellent wear-resistant capacity. Finally, experiments are conducted to verify the performances of micro drill bit with optimized parameters. Experimental results confirm that a micro drill bit with small helix angle and primary face angle as well as optimized helix groove shape is beneficial to drilling environment-friendly PCBs.

1. Introduction

Currently, worldwide PCB industry is experiencing rapid development. The output of world PCB industry continuously increases and the output exceeded 46 billion USD by the end of year 2006. Meanwhile, this inspiring trend will continue in the following years. It is predicted by PRISMARK that the average year-on-year growth rate is around 6% worldwide from year 2006 to 2010. The main development drive of world PCB industry comes from Asia, which accounts for nearly 80% of world PCB output. Now China becomes the largest PCB manufacturing country and the average year-on-year growth rate of PCB industry in China is approximately 14%. With the rapid and stable growth of world PCB industry, the consumption of micro drill bit increases significantly. Worldwide micro drill bit consumption is over 1 billion pieces in year 2006 and this number will increase further. To seize this market opportunity, micro drill bit manufacturers, especially in Asia, are expanding their production capacity. Meanwhile, micro drill bit manufactures have to face more challenges than ever before. For example, the widely used environmental friendly PCBs (including halogen-free PCB and lead-free assembly compatible PCB) limit the drill bit performance as the machinability of these kinds of PCBs is worse.

World PCB industry has entered lead-free era since July 2006, as the two environmental directives of European Union, namely RoHS (Restriction of Hazardous Substances) and WEEE (Waste Electrical and Electronics Equipments), has taken effect. To meet these environmental protection requirements, lead free assembly compatible PCBs become popular. Tg of this kind of PCB is increased and fillers (such as SiO_2, Al_2O_3, $Al(OH)_3$) are frequently added to improve the heat resistance and dimension stability of PCBs. To consider the world's environment and prevent the emergence of dioxin or other hazardous substances when wasted or burned, halogen-free PCB which does not consist of any materials that generate dioxin is used. The typical feature of the machinability of environmental-friendly PCBs is that the material is hard and brittle, the drill bits tend to be broken and the wear get worse.

In this paper, a new type of micro drill bit with excellent performances on drill strength and wear resistant capacity is designed for environmental-friendly PCBs particularly. The objective of this paper is to provide a successful solution to drill environmental-friendly PCBs.

2. Key Points in Micro Drill Bit Design for Environmental-friendly PCBs

In environmental-friendly PCBs drilling, the debris can be evacuated easily compared with drilling of common PCBs. But the machinability of environmental-friendly PCBs is worse compared with common PCBs due to their higher hardness and brittle feature. Thus there are some difficulties in environment-friendly PCBs drilling, two of them are:

1) The drill bit tends to be broken;
2) Too excessive drill wear are frequently observed.

To find the solution of above-mentioned difficulties, the reasons for those difficulties should be analyzed first. One reason for drill breakage is weak strength design, for example the core diameter is too small. Meanwhile, too large drilling torque caused by too excessive wear, blunt cutting edge, and worse debris evacuation condition can also lead to drill breakage. Another drill breakage reason is too excessive bending stress caused by large deformation at the end of flute due to inappropriate rigidity design. The most important reason for too excessive wear is that the hardness of drill bit material is inadequate. At the same time, appropriate helix angle and primary face angle of drill bit should be applied to avoid too excessive wear.

Thus one key point to design a drill bit for environment-friendly PCB is how to ensure the strength to prevent drill breakage. The other point is how to achieve good wear resistant capacity to avoid too excessive drilling wear. Better strength and wear resistant capacity can be obtained via following ways:

1) Improve the strength of whole drill bit;
2) Increase the strength of cutting edge;
3) Keep the balance between strength and debris evacuation;
4) Optimize the helix groove shape;
5) Employ micro drill bit material with adequate hardness.

3. Micro Drill Bit Design

The key parameters of micro drill bit considered in this paper are helix angle, primary face angle, web thickness and helix groove shape.

3.1 Enhance the strength of whole drill bit and cutting edge via helix angle and primary face angle optimal design

One of the important parameters to influence the strength of a whole drill bit is the web thickness. If the front web thickness is too small, the primary face becomes narrow and the wear resistant performance of drill bit becomes worse, the drill bit tends to be broken. Also the rear web thickness influences the drill bit life and the rate of drill breakage. If the rear web thickness is too small, the drill bit tends to be broken during the drilling process. And even worse, the drill bit will be broken at the very beginning of the drilling process. To ensure the strength of a whole drill bit, a big web thickness is recommended.

The strength of cutting edge is mainly determined by the helix angle and primary face angle (see Figure 1). A large helix angle combined with a large primary face angle leads to a sharp cutting edge, while the strength of cutting edge is reduced. On the contrary, better strength of cutting edge can be achieved by adopting a small helix angle and a small primary face

angle. Thus, to design drill bit for environmental friendly PCBs, small helix angle and appropriate primary face angle are employed to achieve the strength of cutting edge and acceptable sharpness.

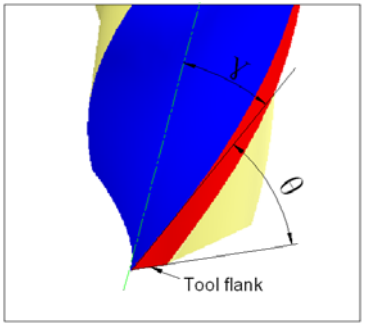
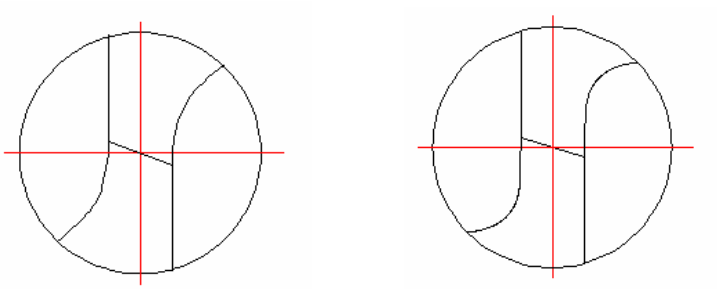


Figure 1 Influences of helix angle and primary face angle on cutting edge strength

3.2 Optimization of helix groove shape

The hole wall roughness is closely related with the chip evacuation conditions. If the chip evacuation becomes difficult, the hole wall roughness gets worse correspondingly. A big helix angle is beneficial to improve the chip evacuation force, but the chip evacuation path becomes longer. In our research, the chip evacuation capability becomes better if a large helix angle is applied when the helix angle varies between 25 degree to 45 degree. If the helix angle increases further, the chip evacuation becomes worse.

As mentioned above, a big web thickness and small helix angle are employed in micro drill bit design for environmental friendly PCB drilling to achieve adequate strength of cutting edge and whole drill bit, but the chip evacuation capability becomes worse by such design. Therefore, other key parameters to influence the chip evacuation capability greatly must be optimized. In this paper, the helix groove shape is considered to improve the chip evacuation capability of drill bit. The optimized helix groove shape is described in Figure 2. It can be easily found that by adopting new design of helix groove shape, the chip evacuation space is increased. Furthermore, by utilizing the finite element analysis (FEM), it is easy to get differences on hole registration accuracy and strength of drill bit between these two designs. The results show that the hole registration accuracy of drill bit with helix groove shape (b) is better than that with helix groove shape (a). Meanwhile, the strength of drill bit with shape (b) is much better than that with shape (a) due to the small helix groove shape differences. Therefore, it is critical to control the helix groove shape of drill bit during its design and manufacturing processes.



(a) Conventional design (b) Optimized design

Figure 2 Comparison of two helix groove shapes

3.3. Composite Structure Design and Coating Techniques

One major challenge in drilling environment-friendly PCBs is how to avoid excessive wear of drill bit. Among the factors that influence the wear resistant performance of drill bit is the material property of drill bit. Thus the ideal tungsten carbide to design micro drill bit for environmental friendly PCBs should have superior hardness. To meet this requirement,

basically tungsten carbide for micro drill bit manufacturing should have excellent properties in grain size, hardness, strength, fracture toughness, heat conductivity, anti and chemical erosion. Grain size in tungsten carbide is critical to the material properties.

The composite micro drill bit with stainless steel shank and tungsten carbide cutting part is designed. Currently, there are two methods to combine the stainless steel rod and tungsten carbide rod. One is called brazing method that the stainless steel shank and tungsten carbide rod with same diameter are brazed together (see Figure 3a). The other is insert-type jointing method that a tungsten carbide rod is inserted into the hole of heated stainless steel shank (see Figure 3b). In this study, brazing method is employed to connect the stainless steel shank and tungsten carbide.

(a) Brazing type (b) Insert type

Figure 3 Two different composite structure

To promote the performances of wear resistant of micro drill bit, coating is attempted. Tool coating technique employs chemical vapour deposition (CVD) or physics vapour deposition (PVD) to obtain ultra hard composite and consolidated material surface. Meanwhile, ion implanting, which is different from ion planting and ion spattering, is concerned by drill bit manufacturer, as it can improve hardness, fatigue resistance, wear resistance, corrosion resistance, oxidation resistance, conductivity and optical property of material surface.

Currently, coating technique is demonstrated successful only in large diameter drill bit and router bit. Most manufactures conduct coating for micro tool by using the technique for large diameter tool, so the results are not satisfied. According to the experiments conducted in Jinzhou, ion implanting is suitable for micro drill, but more efforts need to be paid. The appropriate coating for micro router is high hardness and low friction factor coating such as DLC, diamond, TiN, TiAlN and so on. These coatings can be implemented via magnetic filter cathode vacuum arc deposition (FCVA), plasma chemical vapour deposition (PCVD) and closed field unbalanced magnetron sputter ion plating. Even though there is a long way to go to employ coating techniques in micro tool bits, coating technique still has great potentiality in micro tool bit industry.

4. Experimental Verifications

To examine the performance of designed micro drill bit for environmental friendly PCBs, the experimental verifications are conducted on a HITACHI 6-spindle CNC drilling machine. The drill wear conditions are observed via a digital microscope, the hole registration accuracy are measured via a hole AOI machine and the hole wall roughness is measured through the metallographic microscope. The experimental conditions are listed in Table 1. It should be pointed out that the drilling parameters listed in Table 1 are optimized and appropriate drilling parameters, especially infeed rate and hits limit are critical to ensure the performance of drill bit.

During the experimental process, no drill breakage is observed. The drill bits show good wear resistant performances (see Figure 4), good hole registration accuracy (see Figure 5 and Table 2) and superior hole wall quality (see Figure 6). From the results, it can be found that the designed drill bit for environmental friendly PCBs has excellent overall performances including wear conditions, hole registration accuracy, hole wall roughness and drill breakage rate. The design of drill bit for environmental-friendly PCB is successful.

Table 1 Experimental conditions

PCB	6 layers, 0.8mm thick, 3 panels
Drill size	Φ0.25×4.5
Spindle speed	158 Krpm,
Infeed rate	28mm/s
Retract rate	300 mm/s
Repoint times	2
Hits limit	2000 (new drill), 2000 (after 1st repoint), 2000 (after second repoint)
Entry board	0.2mm thick aluminum sheet
Backup board	2.6mm thick paper board

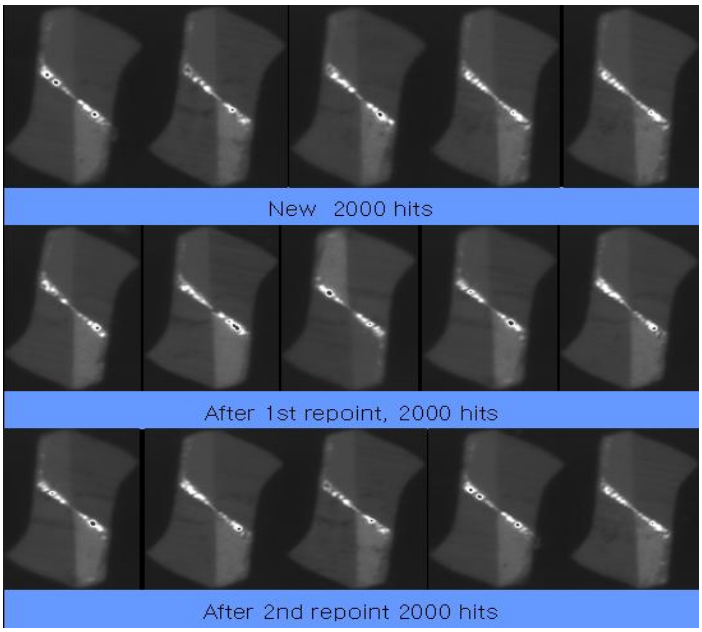


Figure 4 Wear conditions of drill bit

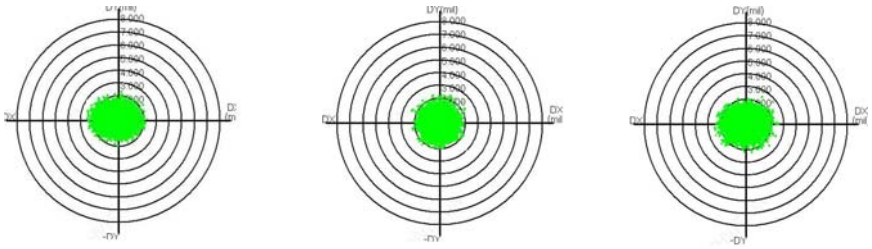


Figure 5 Hole registration accuracy

Table 2 Statistical results of hole registration accuracy

Drill bit	<1 Mil (%)	<2 Mil (%)	<3 Mil (%)	Cpk
New, 2000 hits	80.129	99.687	100.000	2.019
After 1st repoint, 2000 hits	74.437	99.293	100.000	1.893
After 2nd repoint, 2000 hits	73.285	98.503	100.000	1.776

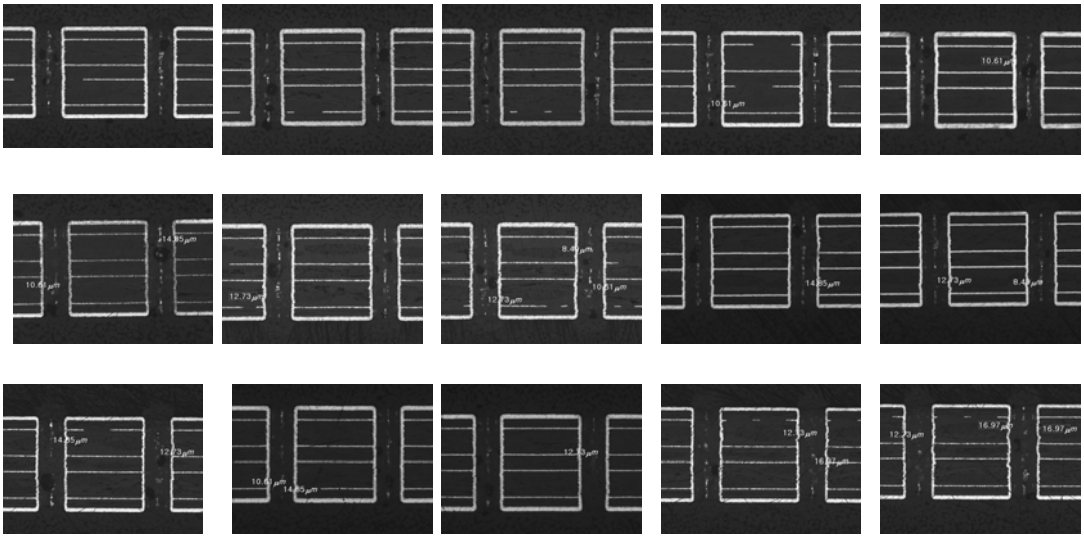


Figure 6 Hole wall roughness results

5. Concluding Remarks

A new type of micro drill bit is designed for environmental-friendly PCBs. The experimental results confirm that big web thickness, small helix angle and optimized helix groove shape are beneficial to drill environmental-friendly PCBs, as the strength of cutting edge and the whole drill bit is ensured. To achieve excellent wear resistant performance, tungsten carbide with higher hardness is recommended. Another point for environmental-friendly PCBs drilling is that appropriate drilling parameters should be employed and generally the hits limit and feed rate should be kept at an appropriate level.

Development of Micro Drill Bit for Drilling Environment-Friendly PCBs

Speaker: Dr. Fu Lianyu

Outline

1. Introduction
2. Design
3. Experiment
4. Conclusions

1 Introduction

Background

- World PCB industry
  - Unchanged: stable growth
  - Change: new PCBs
  - Lead-free assembly compatible PCB
    - Two environmental directives of EU

      RoHS (Restriction of Hazardous Substances)

      WEEE (Waste Electrical and Electronics Equipments)

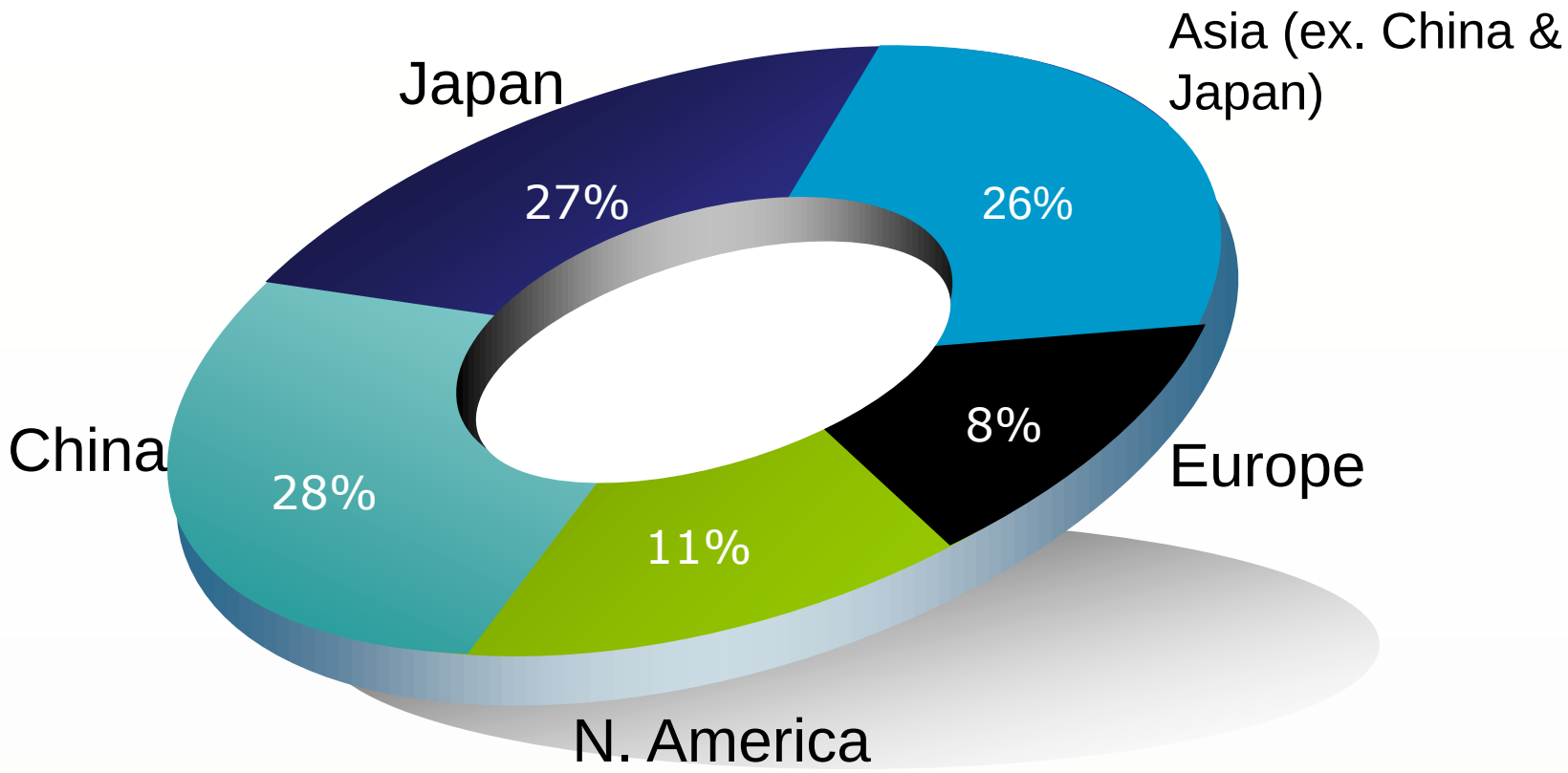
Background

- The widely used environment-friendly PCBs bring more challenges to micro drill bit manufactures than ever before
  - The machinability of these kinds of PCBs get worse
  - Limit the performance of drill bit
- New type of micro drill bit with excellent overall performances is expected
  - Provide a successful solution of drilling halogen-free and lead-free assembly compatible PCBs

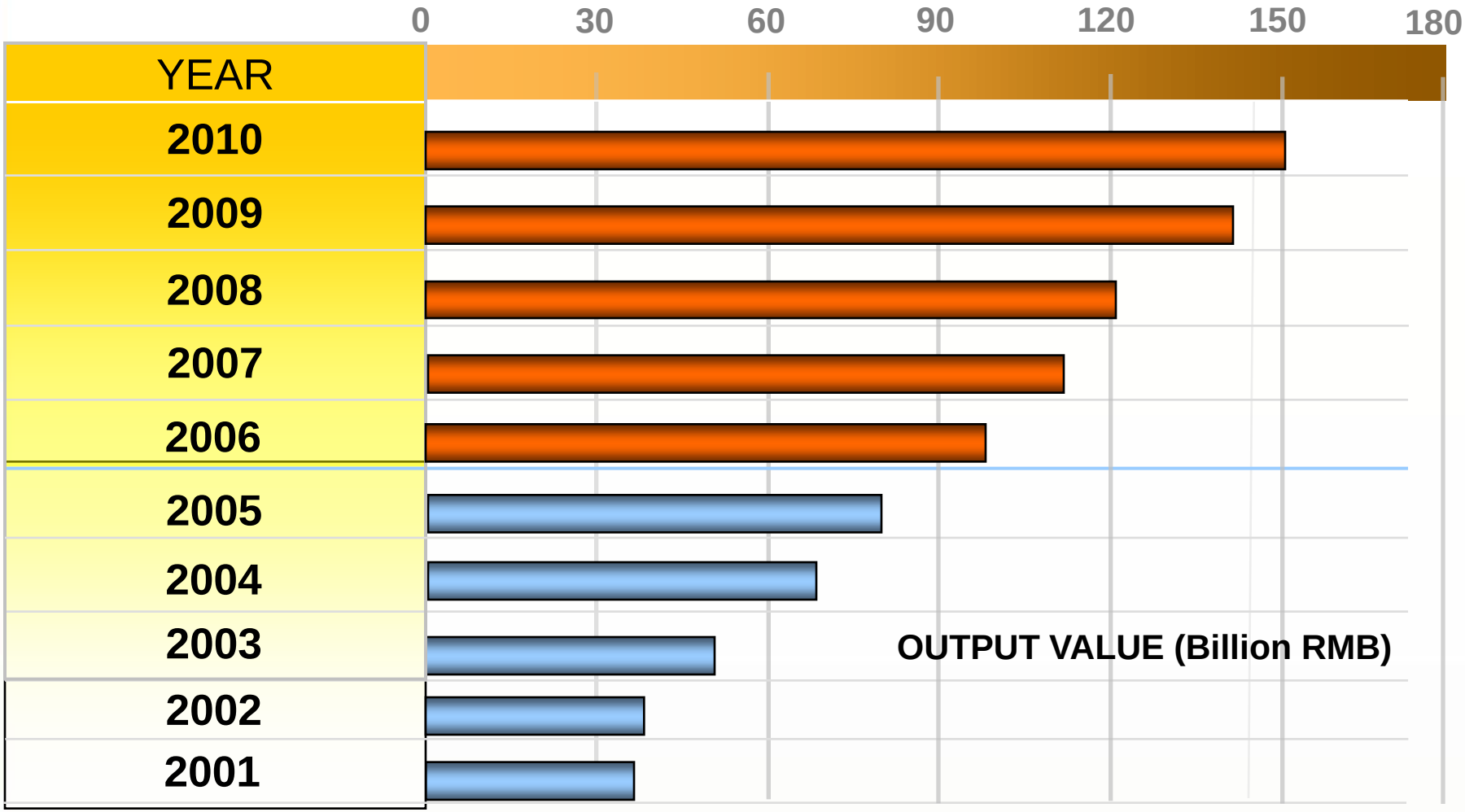
Market opportunity

- The stable growth of world PCB industry
  - By the end of year 2006, the output of world PCB industry has exceeded 46 billion USD
  - Mechanical drilling is still the dominant hole processing method.
  - Worldwide micro drill bit consumption is over 1 billion units.

World PCB Market by Region



China PCB Output



Design

Challenges

Environment-friendly PCBs have higher hardness and brittle feature

The drill bit tends to be broken

Too excessive wear of drill bit

Challenges

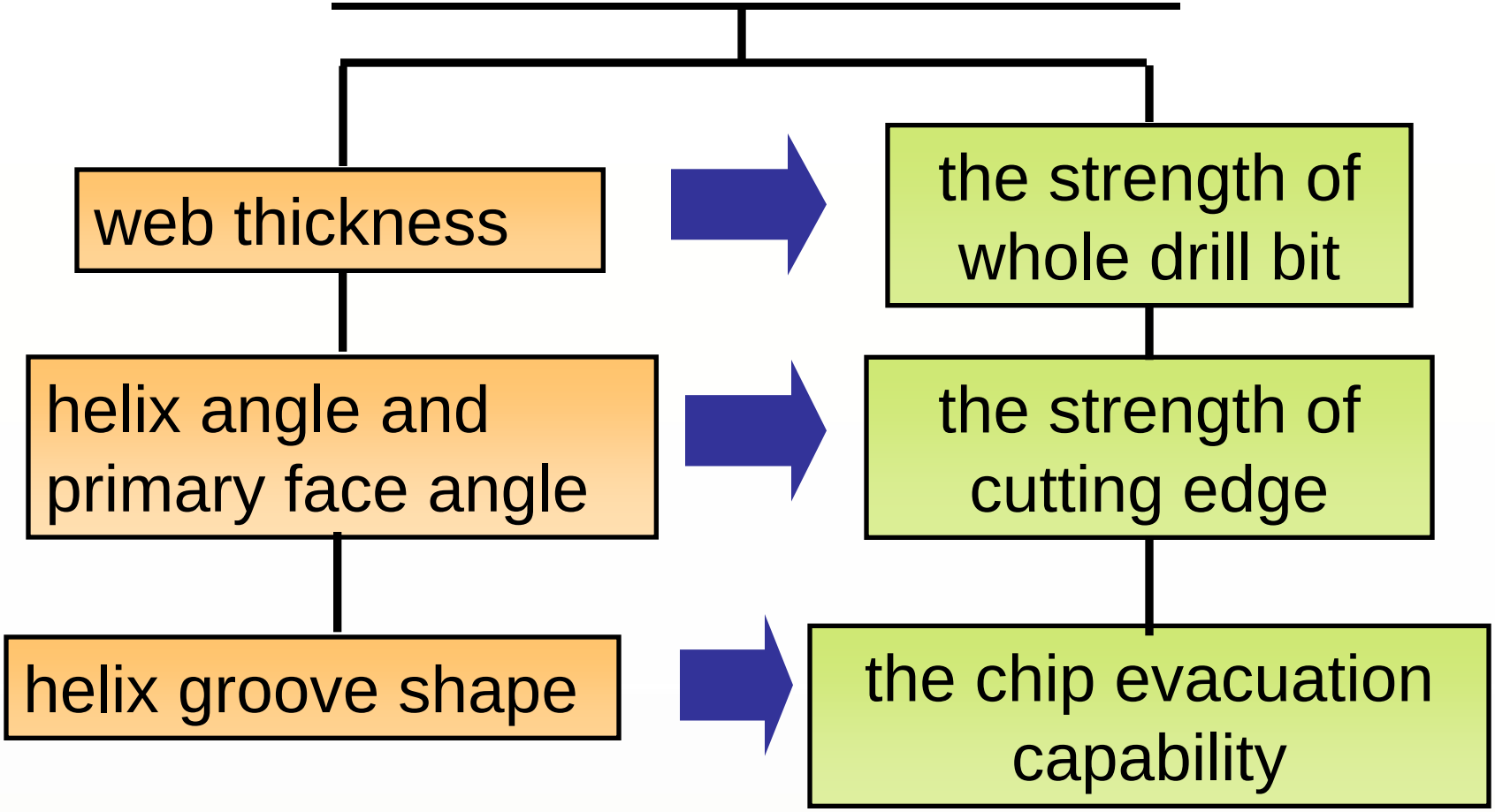
Tools breakag
in environment-
friendly PCBs
processing

- weak strength design
- too large cutting force/torque
- too excessive wear and blunt cutting edge

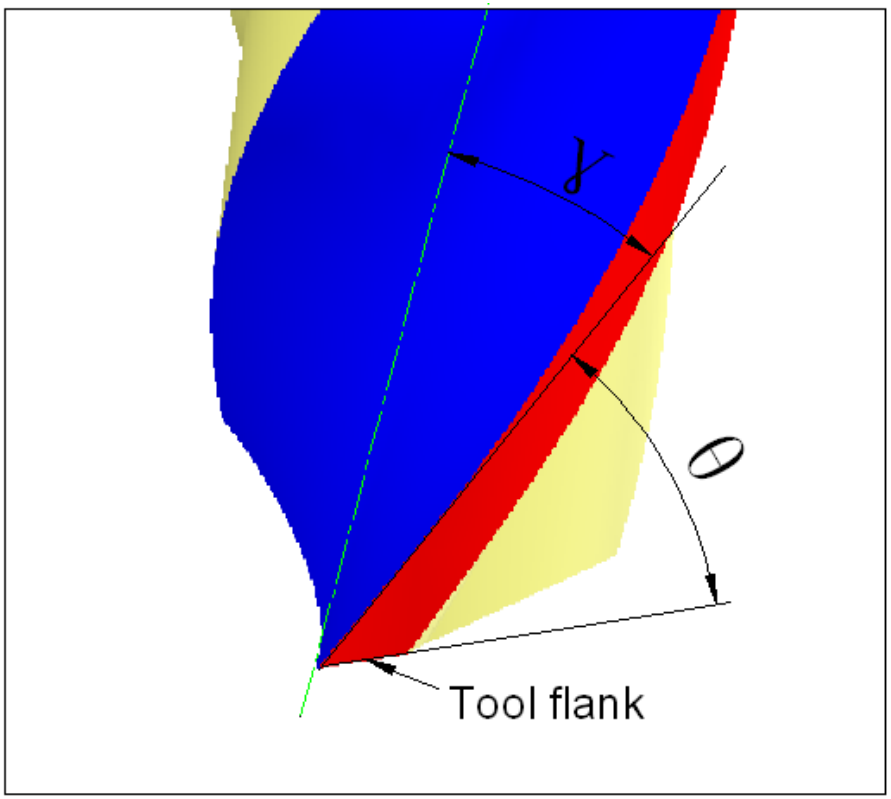
Solutions

- Better strength and wear resistant capacity can be obtained via :
  - Improve the strength of whole tool
  - Increase the strength of cutting edge
  - Optimize the helix groove shape
  - Employ tools material with adequate hardness
- Proper drilling parameters.

Micro drill bit design



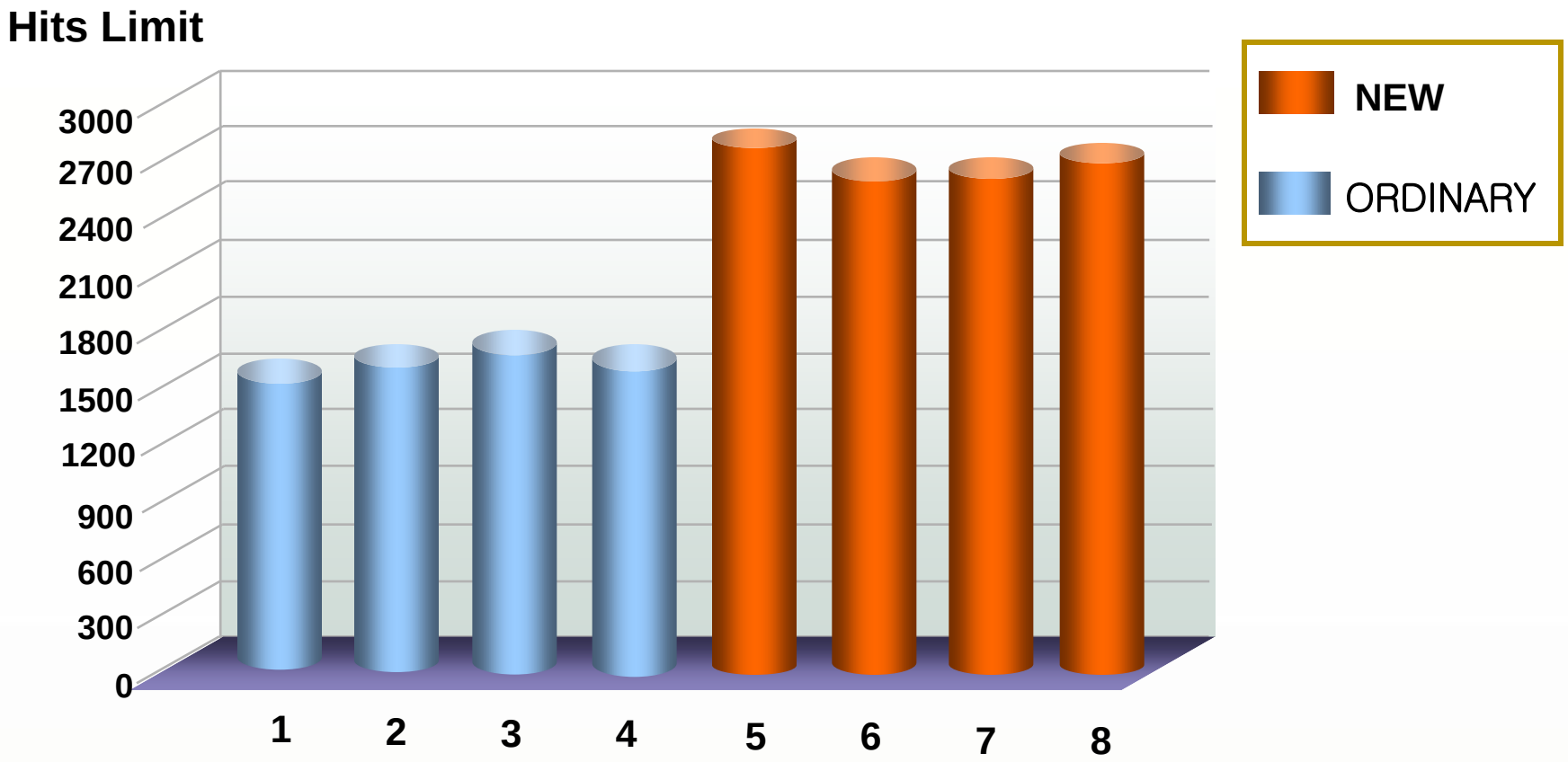
Influences of Helix Angle



Optimization of Helix Groove Shape

- The hole wall roughness is closely related with the chip evacuation conditions.
- The chip evacuation capability becomes worse if big web thickness and small helix angle are employed.
- Therefore, other key parameters to influence the chip evacuation capability greatly must be optimized.
- Here, the helix groove shape optimization is considered.

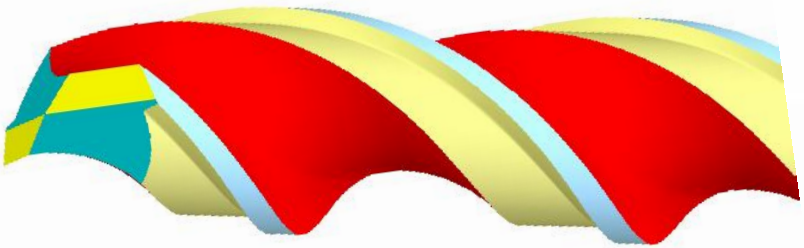
Drill Bit Material



Coating Techniques

- Tool coating technique employs chemical vapour deposition (CVD) or physics vapour deposition (PVD) to obtain ultra hard composite and consolidated material surface
- To improve hardness, fatigue resistance, wear resistance, corrosion resistance, oxidation resistance, and other property of tool surface.
- Coating technique is demonstrated successful only in large diameter drill bit and router bit?
  - NO!

Design examples



3 Experiment

Experiment conditions

Drilling machine	HITACHI ND-6N210E
Wear conditions	Digital microscope
Hole registration accuracy	Hole AOI machine
Hole wall roughness	Metallographic microscope

Experiment conditions

PCB	6 layers, 0.8mm thick, 3 panels, lead-free assembly compatible
Drill size	Φ0.25×4.5
Spindle speed	158 K rpm
Infeed rate	28mm/s
Retract rate	300 mm/s
Hits limit	2000 (new drill), 1500 (after 1st repoint), 1500 (after 2nd repoint)
Entry board	0.2mm thick aluminum sheet
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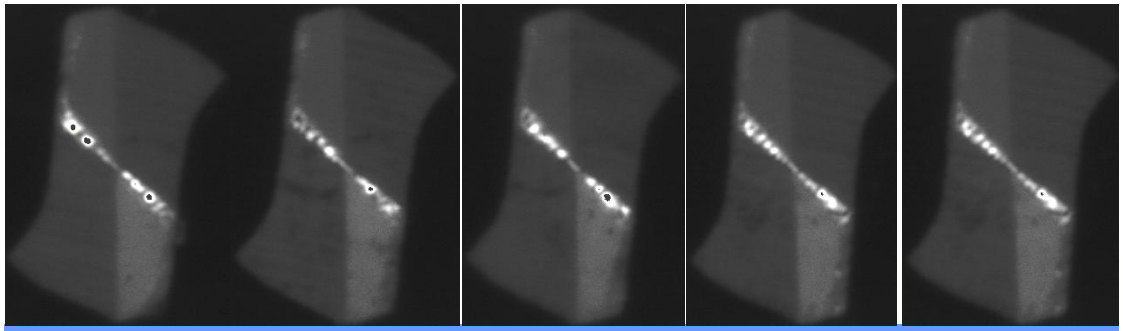
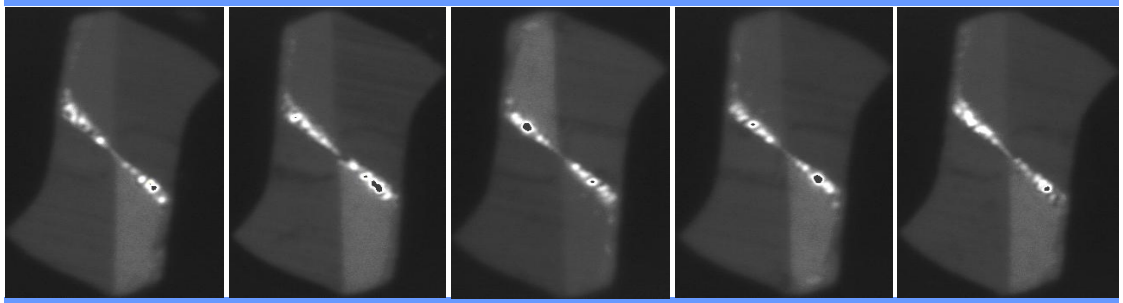
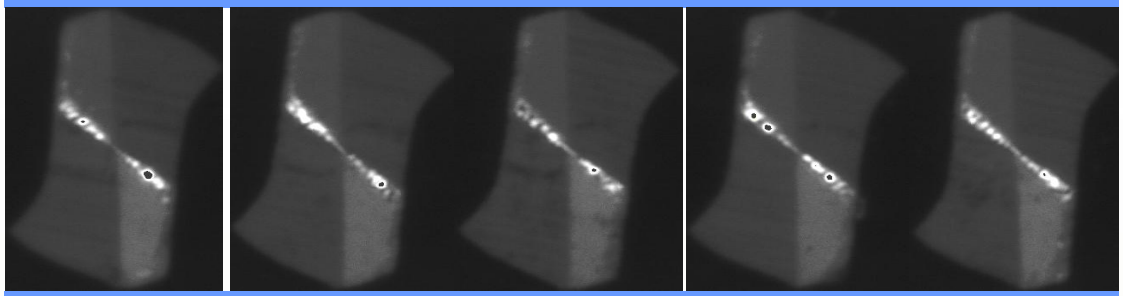
Wear conditions



New 2000 hits

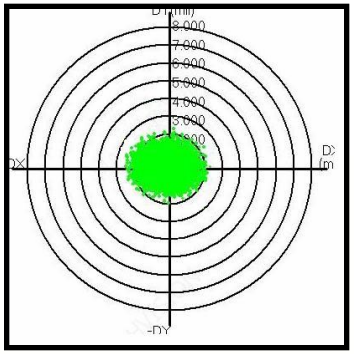


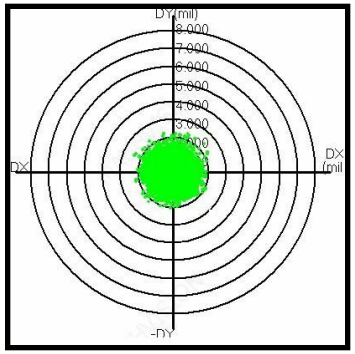
After 1st repoint, 1500 hits

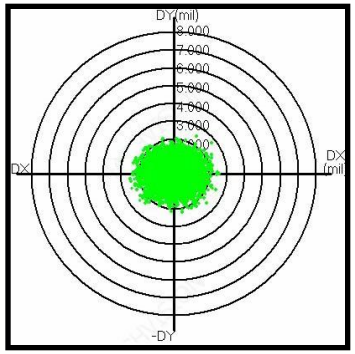


After 2nd repoint 1500 hits

Hole registration accuracy







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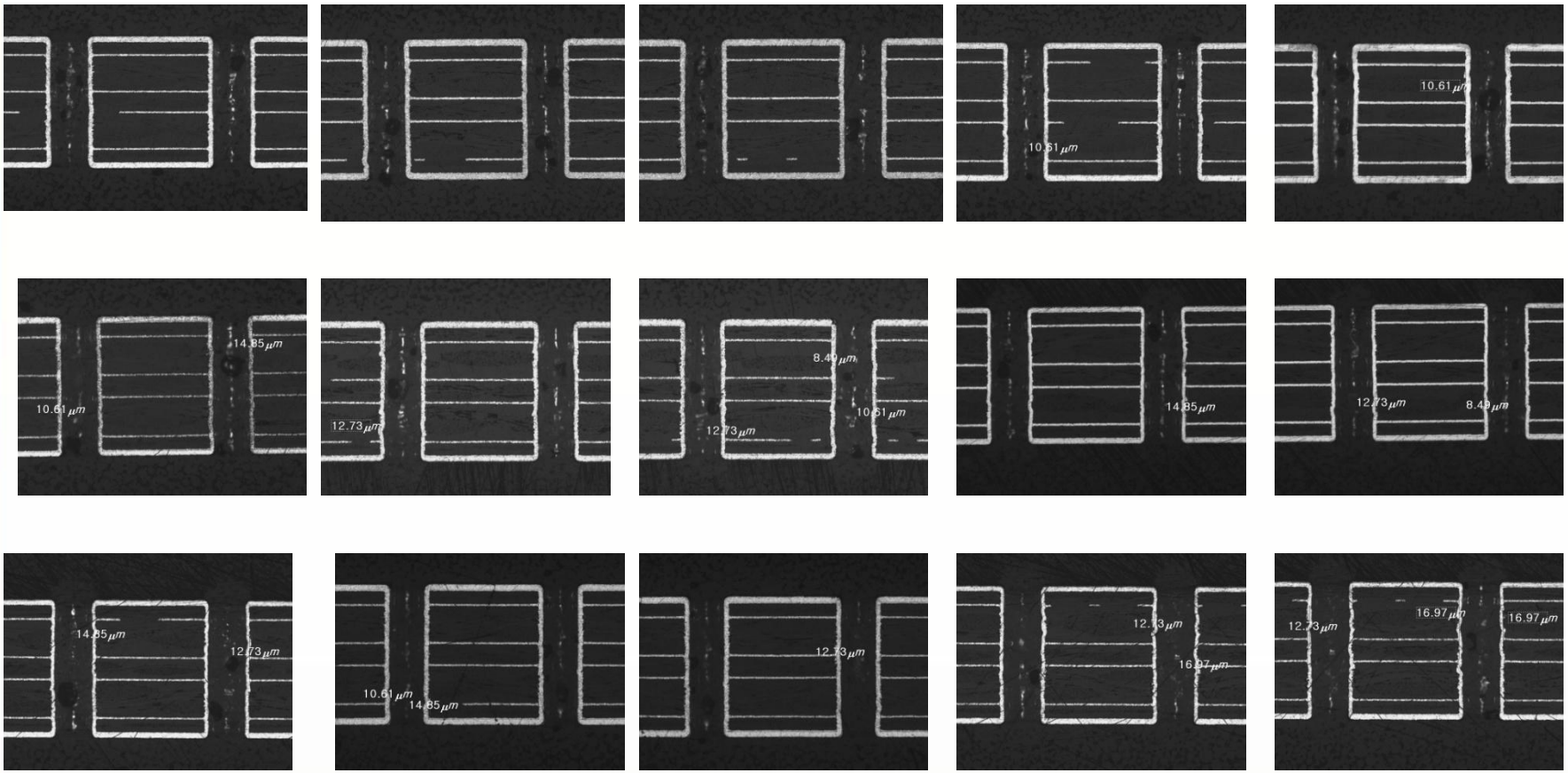
Hole wall roughness



4 Conclusions

Conclusions

1. The basic ideas to design new tools are how to ensure the tool wear resistant capacity and increase the tool life.
2. By employing big web thickness, small helix angle and optimized helix groove shape, the strength of cutting edge and whole micro drill bit are increased significantly.

Conclusions

3. Experimental results confirm that designed micro drill bit has good overall performances and is an appropriate candidate for environment-friendly PCBs processing.
4. Another point for environmental-friendly PCBs drilling is that appropriate drilling parameters should be employed and particularly hits limit should be kept at reasonable level.

Thank You !