Investigation on Drill Wear and Micro Hole Quality in High Speed Drilling of High Frequency Printed Circuit Board

Xianwen Liu, Hongyan Shi*, Guang Huang, Sha Tao and Zhisen Gao

College of Mechatronics and Control Engineering, Shenzhen University, Shenzhen 518060, People’s Republic of China

*Corresponding author’s email: shy-no.1@163.com

Abstract. Due to the severe wear of micro drill and the difficulty in controlling of hole quality, high speed drilling process of high frequency printed circuit board (PCB) was attracted comprehensive attention. In this investigation, the wear width of drills’ primary face was measured, and the wear morphologies of micro drills were studied at once. Furthermore, regularity of micro hole quality concerning drilling burr and nail heading while drilling with different types of drills were analyzed. The research results indicated that the wear width of diamond coating drill reduced slightly. Abrasive wear and adhesive wear were mainly occurred on uncoated drill and diamond like carbon coating drill, but some micro breaches and pits appeared on uncoated drill. Meanwhile, drilling with diamond like carbon coating drill could obtain better hole quality than drilling with uncoated ones. However, diamond coating drill performed well in terms of ability of wear resistance, as well as micro hole quality.

1. Introduction

Transmission of high frequency signal required the high frequency PCB with the properties of lower dissipation factor (Df), lower dielectric constant (Dk) and lower coefficient of thermal expansion (CTE). Yet materials in high frequency PCBs, such as polytetrafluoroethylene (PTFE) and ceramic filler, which usually cause micro drill wear severely and bring the difficulty in controlling of hole quality during the high speed drilling.

There were many studies regarding the micro hole drilling of PCBs. With respect to drill wear, Rawat et al. demonstrated the wear mechanisms of micro drills, and they found that the friction between drill and materials raised the drilling temperature, and aggravated drill wear. Furthermore, abrasive wear mainly occurred on primary cutting edge of drill[1]. Iliescu et al. presented an effective method to predict tool wear, which was validated via the drilling experiments, so that it provided a reference to investigate the drill wear in the high speed drilling process of high frequency PCBs [2]. In order to study the wear mechanisms of micro drill, the morphologies of drills were observed, and the flank wear of the micro drills was measured, and the factors affected flank wear were studied by Zheng et al. [3]. Imran et al. created a characteristic wear map of cutting conditions which aimed at helping to identify the zones of lowest wear rate, so it provided a valid method for selecting suitable cutting parameters for micro drilling [4].

In aspect of micro hole quality, the effect of drilling parameters (spindle speed and feed rate) to micro hole quality was studied [5-9]. Guo et al. found that with the decrease of chisel edge length, drilling with thinned micro drill could get smaller entrance burrs, less roundness errors, and regular shapes. Meanwhile, drilling with thinned chisel edge generated more small-size chips, as well as
improved chip breaking [10]. Nakagawa et al. depicted that it was of great importance to reduce the workload for the sake of excellent hole quality [11]. Shi et al. maintained that coating technique in micro drill was the trend while considered to improve the ability of wear resistance for micro drill, and they reviewed the major techniques which regarding micro hole drilling of high speed PCB and high frequency PCB [12].

Micro hole drilling was of significance to the fabrication of high frequency PCB, in view of the challenges in micro drilling of high frequency PCB, investigation concerning drill wear and micro hole quality were meaningful and necessary. In this paper, wear width of the uncoated drill and coating drills were measured after a given number of holes were finished, and the wear morphologies were observed simultaneously. Additionally, micro hole quality, including drilling burr and nail heading, while drilling with different types of drills were investigated.

2. Experiment and method

2.1 Materials

A kind of high frequency PCB was treated as the process object in this experiment, which model was RO3003, mainly consisted of copper foil, PTFE and ceramic filler. The combination of aluminum sheet and cold punching plate were used to be the entry board, the phenol aldehyde board was used for back board. The laminated construction of those materials, therefore, was shown as figure 1.

![Laminated construction of materials](image)

Figure 1. Laminated construction of materials.

Three types of drills which with the same geometry structure were prepared for the drilling process, and they were named uncoated drill, diamond like carbon coating drill and diamond coating drill, respectively. Therein, diamond like carbon coating drill was fabricated through physical vapor deposition, and this kind of coating with low friction coefficient. Diamond coating drill was fabricated via chemical vapor deposition, which was processed under hydrocarbon atmosphere.

2.2 Experiment method

Firstly, the drilling parameters, such as spindle speed, feed rate and retract rate were selected through the consideration of drill diameters and the drilling experiments, they were listed as, spindle speed: 155 krpm; feed rate: 40 mm/s; retract rate: 300 mm/s.

Additionally, in order to find out the influence of high frequency PCB to the drill wear, the width of drill’s primary face would be measured via microscope (OLYMPUS, model: SZ61TRC) after drilling a certain holes for each kind of drill. The wear width (w) was calculated through the following equation (1):

\[ w = L_0 + L_0 - (L_n + L_n) \]  

(1)

Where, \( L_0 \) and \( L_0 \) were the width of primary face of new tool, \( L_n \) and \( L_n \) were the width of primary face of the drill which drilled a certain number of holes, the subscript \( n \) identified the sequences of measurement (\( n = 1, 2, 3, 4, 5, 6, 7 \)). Consequently, the measuring principle as shown in figure 2. Also, the wear rate (\( R \)) was defined by the following equation (2):
\[ R = \frac{W}{L_0 + L_n} \times 100\% \]  

(2)

The wear morphologies of three types of drills were going to be observed through scanning electron microscope (FEI company, model: Quanta FEG 450). Micro hole quality of high frequency PCB, including drilling burr and nail heading would be compared while using different drills. Therein, the height of drilling burr and nail heading were measured through microscope. Moreover, the height of drilling burr and the value of nail heading were the mean value in each measurement period. The method of measurement was shown as figure 3, \( H_1, H_2 \) represented the height of drill burr (figure 3a), and the nail heading was expressed by the value of \( B \) divided by \( A \) (figure 3b).

**Figure 2.** Measurement of wear width  
**Figure 3.** Measurement of drilling burr (a) and nail heading (b) [13]

3. Results and discussions

3.1 Drill wear

3.1.1 Wear width of drill’s primary face. Comparisons of primary face between the new drills and the drills finished 1200 holes were shown as figure 4, figure 5, and figure 6. These figures showed that the primary face of uncoated drill and diamond like carbon coating drill were worn severely when they drilled 1200 holes. The wear width for uncoated drill and diamond like carbon coating drill were 77.9 μm and 70.1 μm. Furthermore, there were some resins adhered on the secondary face where near chisel edge for each kind of drill, and the most serious adhesion occurred on uncoated drill, it might because the roughness of that positions was worse.

The details of wear width variations were shown as figure 7, which indicated that the wear width of diamond like carbon coating drill was less than uncoated drill after drilling same number of holes, but the diamond coating drill showed the best performance while considered the wear width of primary face. Meanwhile, it was clear that the wear width was increased tremendously while finished 100 holes for uncoated drill and diamond like carbon coating drill, and then increased at slower rate in the following process. The reason to explained this phenomenon was that the primary cutting edges of uncoated drill and diamond like carbon coating drill were loaded heavy pressure at that period. The wear width of diamond coating drill, however, rose slightly and steadily during the whole drilling period, it was only 11.63 μm after drilling 1200 holes.

**Figure 4.** Comparison of uncoated drill before and after drilling
In terms of wear rate, there were 64.9%, 65.4%, 10.0% for uncoated drill, diamond like carbon coating drill and diamond coating drill, respectively. These results illuminated that diamond coating drill had excellent ability of wear resistance. Moreover, these two kinds of coated drills were propitious to reduce the wear width of micro drill in the micro hole drilling of high frequency PCB.

3.1.2 Wear morphology. In this part, each figure were divided into part (a) and part (b), and part (b) was the partial enlargement of part (a). Wear morphologies of uncoated drill were shown in figure 8, figure 9 and figure 10. The breach occurred on the primary cutting edge (figure 8), it might be explained that the wallop while drilling ceramic fillers made the primary cutting edge arose brittle rupture, especially when the cutting edge was sharp. This form of wear would directly decrease the drill’s cutting ability. Some pits appeared near chisel edge (figure 9), that was mainly because chisel edge and drilling object engendered strong squeezing action, which caused the temperature around this position went up quickly, so that the cohesive action from cobalt decreased and the micro grains that consisted of drill fell off easily. In addition, the fracture on land (figure 10) was caused by the friction from the hole wall and extrusion pressure from chips, particularly the chips were made of copper foil and ceramic filler.
Wear morphologies of diamond like carbon coating drill were shown in Figure 11, Figure 12 and Figure 13. The wear on primary cutting edge and chisel edge were similar as uncoated drill, yet the boundary between coating and raw materials was palpable and clear in these two areas, and the phenomenon of coating thinned was observed on land of drill (Figure 13). The abrasive wear and adhesion wear were the main forms on primary cutting edge and chisel edge, and coating shedding was occurred in these two areas. Additionally, because the land was a part of cylinder, the friction action on land would be more balanced, so the coating on land took on thinned trend with increment of drilled hole. Moreover, no breach or pit were found around primary cutting edge, chisel edge and land.

Figure 8. Wear morphology around primary cutting edge of uncoated drill

Figure 9. Wear morphology around chisel edge of uncoated drill

Figure 10. Wear morphology around land of uncoated drill

Figure 11. Wear morphology around primary cutting edge of diamond like carbon coating drill
Figure 12. Wear morphology around chisel edge of diamond like carbon coating drill

Figure 13. Wear morphology around land of diamond like carbon coating drill

Wear morphologies of diamond coating drill were shown in figure 14, figure 15. Firstly, some copper chips adhered near the primary cutting edge, and the coating on primary cutting edge and side-cutting edge caused them not as sharp as the uncoated drill and diamond like carbon coating drill. But the outlines of primary cutting edge and side-cutting edge were kept well as the new tool, no coating shedding or breach occurred on all places. This kind of coating, therefore, displayed excellent ability of wear resistance and predominant adhesion with micro drill matrix.

Figure 14. Wear morphology around primary cutting edge of diamond coating drill

Figure 15. Wear morphology around side-cutting edge of diamond coating drill

3.2 Micro hole quality

3.2.1 Drilling burr. The variations of drilling burr after a given number of drilled holes were shown as figure 16. The result indicated that the height of drilling burr was really short before drilling 200 holes, especially drilling with uncoated drill and diamond like carbon coating drill. That was because the cutting edges of drills still kept sharp. But drilling with diamond like carbon coating drill could obtained shorter drilling burr than drilling with uncoated drill in every measurement stage. The height of drilling burr was increased gradually after drilling 200 holes, from 2.69 μm to 21.61 μm while drilling with uncoated drill, and from 0.34 μm to 19.69 μm while drilling with diamond like carbon
coating drill. For diamond coating drill, the height of drilling burr held a slight fluctuation in the three measurement stages. Besides, the height of drilling burr kept less than 7 μm steadily in each measurement stage.

![Variations of drilling burr in different drilling stages](image1)

**Figure 16.** Variations of drilling burr in different drilling stages

With regard to the variation of drilling burr while drilling with uncoated drill and diamond like carbon coating drill, since the wear width increased and the primary cutting edges rusted with the increment of drilled number, the drilling performance became weaker, and drilling burr increased gradually. Furthermore, the height of drilling burr was stable and short while drilling with diamond coating drill, this superiority on drilling burr may be explained by the excellent ability of wear resistance of diamond coating drill, and this ability kept the cutting edge sharp for a long term.

3.2.2 **Nail heading.** As figure 17 shown, regularity on nail heading was similar with the trend of drilling burr. The nail heading increased with the increment of drilled number while drilling with uncoated drill and diamond like carbon coating drill, meanwhile the nail heading reached to 1.89 and 1.71, respectively, while the uncoated drill and diamond like carbon coating drill finished 1200 holes. But for the process using diamond coating drill, the nail heading became smaller with the increase of drilled number.

![Variations of nail heading in different drilling stages](image2)

**Figure 17.** Variations of nail heading in different drilling stages

According to the results we could know that the wear width of primary face was the most
significant factor when considering the variation of nail heading, because the changes of wear width reflected the develop trend of nail heading, such as the nail heading’s variations while drilling with uncoated drill and diamond like carbon coating drill. But the biggest nail heading occurred when drilling 200 holes, that might because the cutting edge of diamond coating drill was blunt at that period. Meanwhile, the variation trend of nail heading was a little different to the drilling burr while drilling with diamond coating drill, that meant the sharpness of primary cutting edge, side-cutting edge and other factors ought to be considered when we desired to find out the influence factors of nail heading and drilling burr more synthetically.

4. Conclusion
Drill wear, drilling burr and nail heading in micro hole drilling of high frequency PCB were investigated in this study. In aspect of drill wear, the wear width for uncoated drill, diamond like carbon coating drill and diamond coating drill were 77.9 μm, 70.1 μm, and 11.6 μm, respectively, after drilling 1200 holes, furthermore, their wear rates were 64.9%, 65.4%, 10.0%, respectively. Thus, the coating drills indicated the better performance in terms of wear width, especially for the diamond coating drill. Abrasive wear and adhesive wear were mainly occurred for uncoated drill and diamond like carbon coating drill, and some pits and breaches appeared on uncoated drill. The boundary between coating and raw materials was palpable and clear on diamond like carbon coating drill, but the phenomenon of coating thinned was still observed on land. The outlines of primary cutting edge and side-cutting edge maintained well as the new tool, no coating shedding and breach were found on every position of diamond coating drill.

In addition, diamond like carbon coating drill performed better than the uncoated drill on drilling burr and nail heading. Because of the excellent ability of wear resistance of diamond coating drill, the height values of drilling burr was steady and short, but the nail heading became smaller while its cutting edge became sharper. However, further study regarding drilling with diamond coating drill was encouraged simultaneously.

Consequently, study on drill wear revealed the wear mechanism of the micro drills, it would provide a guideline for improving the ability of wear resistance of micro drill. Moreover, these two types of coating drills were beneficial to raise the hole quality in high speed drilling of high frequency PCBs.

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