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Greening PCB Drilling Process: Burr Minimization and Other Strategies

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The growing demand for cell phones and other electronic devices in daily life has created a strong need for printed circuit boards (PCBs). The global PCB production value was $46.8 billion in 2010 and is expected to grow in the coming years. Drilling in PCB production cannot be avoided for either electro-connection among layers or fixing components. The formation of drilling burrs affects the PCB quality and results in necessity of a deburring process. The burrs produced from drilling processes can be hard to remove and the cost of deburring is always substantial. Minimizing the creation of burrs during the drilling process will reduce the effort and time needed to remove burrs. Therefore, the hole drilling and deburring process are considered opportunities to reduce energy use. In this paper, the burr formation mechanism for holes was studied. Since burr formation is strongly related to process conditions and drill geometry, experiments were carried out to develop a Drilling Burr Control Chart by varying feed, spindle speed and drill diameter. The Drilling Burr Control Chart serves as a tool to predict burr formation and is therefore extremely useful for industrial applications. This paper proposes several approaches to minimize drilling burrs and to green the PCB drilling process.

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NOMENCLATURE

d = drill diameter
DBCC = Drilling Burr Control Chart
f = feed
F_n= a non-dimensional feed parameter
IT = Information Technology
N = spindle speed
S = a cutting speed parameter
PCB = Printed Circuit Board

1. Introduction and Background

According to the printed circuit report done by Prismark in 2010, global printed circuit board (PCB) market value in 2010 was $46.8 billion and is projected to register about $53.2 billion by the year 2014 [1]. As people's demand for IT products is growing, the demands for circuit boards will keep growing. Prismark forecasted that the average growth rate for global PCB market value from 2009 to 2014 is 5.2% per year.

The raw materials used to produce PCBs are copper and glass fiber reinforced polymer. The conducting layers are made of thin copper foil and the insulating layers are laminated with epoxy. The hole drilling step occurs when printed circuit boards have already gained a high value. The holes drilled through PCB are used for either electro-connection among layers or fixing components. For the former, the inside surfaces of the holes designed to provide a conductive circuit from one side of the board to the other are plated with copper. For the latter, non-conducting holes are plugged to keep them from being plated.

The target of this study is hole drilling in PCBs that influences the deburring process. The scale of the burrs produced from drilling in PCB production is small and, therefore, these burrs are usually difficult to remove. Hence, the hole drilling and deburr process are considered to be opportunities to reduce energy use. In order to improve the efficiency of producing PCBs and decrease the damage to the environment, this paper deals with the hole-drilling step in the production of PCBs.

2. Drilling Burr Formation

Understanding the formation of drilling burr is especially important to predict burr dimension and to minimize burr generation. Burr is plastically deformed material, generated on the part edge during machining. The drilling process produces burrs on both entrance and exit surfaces of a workpiece. Therefore, drilling burrs can be classified as entrance burrs and exit burrs. The entrance burr is formed around the drilled hole in the form of a small wedge, and the exit burr is formed on the other side, when the drill pierces the workpiece by pushing out uncut material volume [2].

2.1 Entrance Burr

The drilling burr that forms at the entrance of the hole can be a result of tearing, a bending action followed by clean shearing, or lateral extrusion. If one thinks of the drill lip as a lathe tool entering the hole, it looks similar to Fig.1 [2]. Entrance burr is usually considerably smaller than the exit burr and is usually of little concern.

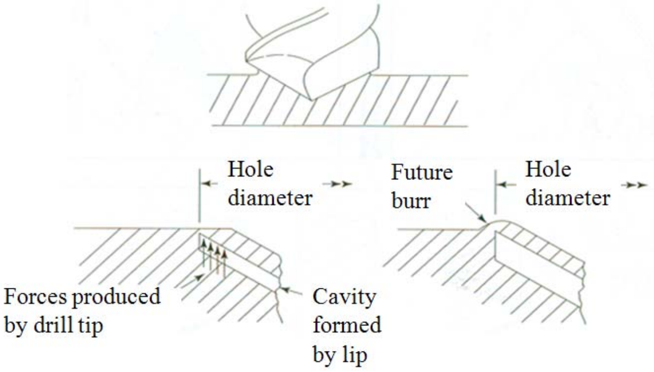

Fig.1 Burr Formation at hole entrance [2]

2.2Exit Burr

The burr that is formed when a sharp drill exits the workpiece is a so-called Poisson burr resulting from rubbing at the margins of the drill. When the drill exits the workpiece the uncut chip rolls, a uniform burr with cap was formed as shown in Fig. 2.

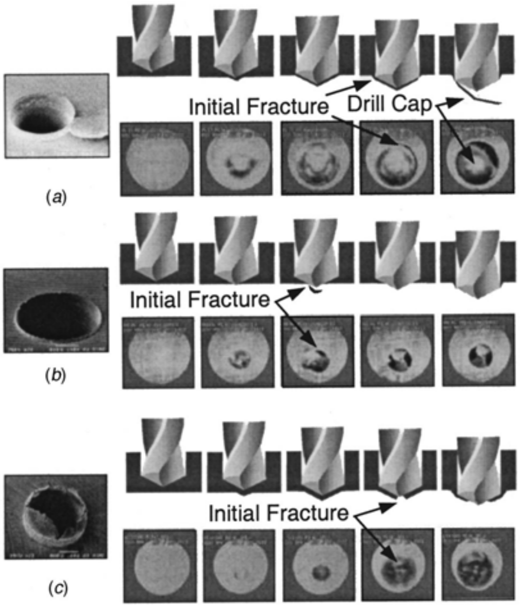

Fig. 2 Burr formation mechanisms (a) uniform burr with a cap (b) uniform burr without a cap (c) crown burr[3]

Figure 2 describes the formation of an exit burr in drilling. As the drill approaches the exit surface, the workpiece deflects and then plastically deforms due to the thrust force created by the drill. Once this deformation is initiated, the deformation increases as the drill cuts more of the workpiece material. When the drill exits the workpiece, the remaining material deflects creating an exit burr. [2, 4]

2.3Drilling Parameters

Understanding what and how parameters influence the drilling process is very helpful. The drilling burr formation is a very complicated phenomenon which is affected by many factors as shown in Table 1.

Table 1 Parameters affecting drilling burr formation [11]

Category	**Parameters**
Drill geometry	Point geometry, point angle, helix angle, lip relief angle, …
Material Properties	Hardness, strain-hardening characteristics, ductility, tensile toughness, temperature and strain rate dependence of properties, …
Process Conditions	Cutting speed, feed, use of coolant, use of pecking, …
Others	Tool wear, tool material, built-up-edge, …

A larger helix angle leads to a larger debris evacuation force and the debris can be evacuated more easily. It has been proven experimentally that debris evacuation conditions and hole wall quality improve if a helix angle between 25° to 45°is applied . If the helix angle increases further, the chip evacuation conditions become worse and the hole wall quality also becomes worse. [12]

The properties of micro drill bit materials are also key characteristics in determining the performance of the bits, especially when the diameter of the drill bit is small. The micro drill bit discussed in [12] by Fu and Yang is designed to achieve less than 10μm hole wall roughness. To satisfy the requirement of strict hole wall quality, micro drill bit materials should have small grain size, high hardness and high transverse rupture strength. [12]

High feeds are thought to increase the drilling thrust. Increased values of thrust cause the plastic deformation of the supporting material underneath the drill point to begin earlier, when the drill is greater distance from the exit surface of the hole, as compared to lower values of thrust. According to [13], decreasing feed rate reduces both the burr height and thickness.

The following section presents an analysis of the influence of drill geometry and process conditions (e.g., feed rate and spindle speed) based on the method of Drilling Burr Control Charts.

3. Drilling Burr Control Chart

The costs associated with removing burrs are substantial. German automotive and machine tool industries conducted a study to analyze costs associated with burr minimization, deburring and part cleaning. The participants of the survey were asked to name the manufacturing share related to burrs for a specific workpiece. In manpower and cycle times, the respondents reported an increase in expenses of about

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15 % due to burrs. Moreover, a 2% share in the reject rate and a 4% share in machine breakdown times due to burrs was reported. [14, 15] Therefore, a better strategy is to minimize burrs or prevent burrs from occurring in the first place. Since burr minimization and prevention is strongly related to process conditions and drill geometry, the whole process has to be considered regarding quality and productivity. Drilling burr control charts (DBCCs) are extremely useful for industrial applications, since a process planner can look at the control chart and see the type (i.e., size and shape) of burr that is expected under specific cutting conditions.

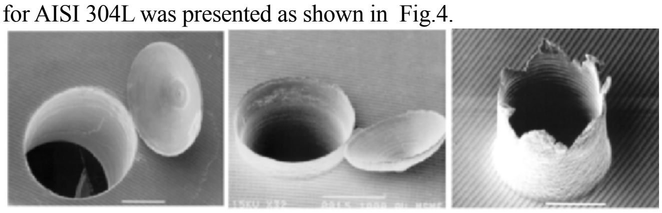
3.1Background

The major process parameters which influence the burr size and shape observed in experiments are feed and spindle speed. It is reasonable to represent possible ranges of operating conditions for drilling by use of a "burr control chart" derived from experimental data on burr formation for varying speeds and feeds.[4] The Drilling Burr Control Chart (DBCC) was developed by Jinsoo Kim in the Laboratory for Manufacturing and Sustainability at UC Berkeley [16]. DBCC quantifies the effect of feed rate and spindle speed on burr type. A dimensionless feed parameter of drilling is the feed parameter, Fn, equal to the feed divided by tool diameter, and it is used along the horizontal axis of the chart. Along the vertical axis the cutting speed parameter, S, is represented. These parameters are given by equation 1 and 2.

$$F_n = f/d \quad (1)$$
$$S = K \cdot d \cdot N \text{ , } K = 10^{-5} \quad (2)$$

F_n is a non-dimensional feed parameter, S is a cutting speed parameter, and K is a constant which makes the order of the two parameters equal.

Control charts for drilling burr formation for stainless, AISI 304L, and low alloy steel, AISI 4118, were developed [8].Three types of burr are defined as shown in Fig.3. Type 1 is a uniform burr with smaller burr height. Type 2 is also a uniform burr with a relatively large burr height. Type 3 is a crown burr which has no drill cap and a larger and irregular height distribution around the hole. The DBCC for AISI 304L was presented as shown in Fig.4.



Type 1	Type 2	Type 3

Fig.3 Three types of drilling burr for steel [4]

However, there is no research about DBCC for multilayer material. Based on above described concept, we developed DBCC for exit burr produced by drilling PCB. Burr classification was carried out based on scanning electron microscope (SEM) images. Two types of burrs - uniform burr, and transient burr - and the breakage of the drill were defined. The uniform burr had relatively small and uniform burr height. The transient burr was the transition stage between uniform and drill breakage.

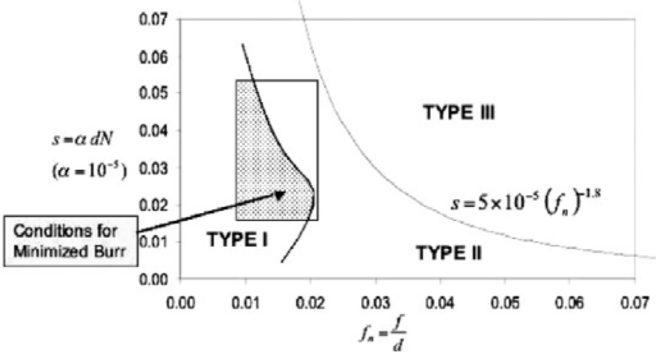


Fig.4 Drilling burr control chart for AISI 304L [4]

3.2 Experiment

Drilling experiments with different feed to diameter ratios, cutting speeds and 400μm, 600μm, 800μm diameter drills were conducted. A 3-axis stage high-speed spindle and cooling devices were used for the drilling experiments. The influence of the cutting parameters on burr size and burr type was observed. The simplified experiment setup is schematically shown in Fig.5. Three stacks of PCBs were drilled with an entry board and a backup board. Most drilling processes create a burr on both entrance and exit surfaces. The exit burr is much larger in size and is the main concern in this study.

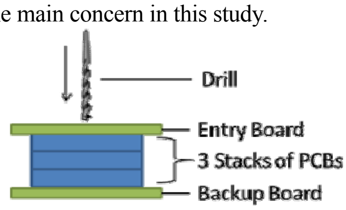


Fig.5 Experiment setup for drilling tests

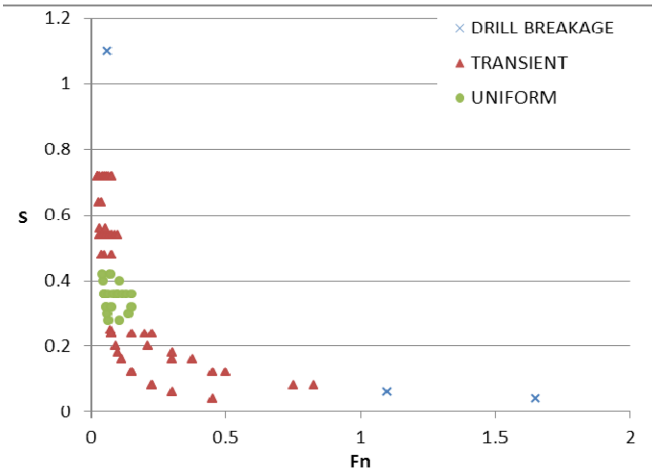


Fig.6 Drilling burr control chart for PCB

A uniform burr is the smallest and is thus preferred. The uniform burr zone in Fig.6 indicates an optimized range of operating conditions. Based on the experiments completed thus far, the burr type is strongly dependent on the product of spindle speed and diameter. If increasing productivity by using high spindle speed is desired, then a small diameter is needed to obtain uniform burrs. Future work will include improving burr quantification methods, presenting DBCC with burr size, and doing more experiments to determine the relationship between tool wear and burr size.

4. Strategies for Greening PCB Drilling Process

Since deburring is a very time consuming and costly operation, the understanding and control of burr formation is a research topic which is very practical for industrial applications. In the following section, we proposed possible strategies not only to minimize burr formation, but also to green the entire PCB drilling process.

4.1 Drilling Conditions

Since the drilling burr is strongly related to process conditions, drilling burr minimization can be achieved by applying proper drilling conditions. According to the DBCC developed in 3.2, optimized parameters for the drilling operation can be chosen.

4.2 Tool Life

From the experimental data, there is a tendency for the burr size to increase as the tool gets dull as shown in Fig.7. As burr size increased with the number of holes drilled, the bottom burr required a deburring operation. Therefore, it will be helpful to conduct an experiment to derive the relationship between the numbers of holes drilled and burr size as shown in Fig.8.

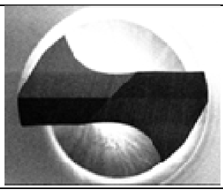
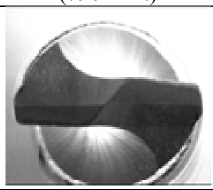
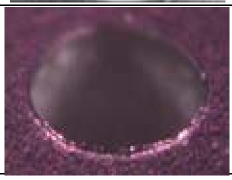
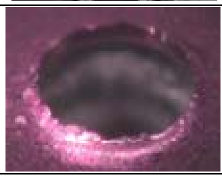
	1st drilling tests	After drilling tests (790th hit)
Wear on the top of drill		
Drilling Burr		

Fig.7 Comparison of drill wear and burr height

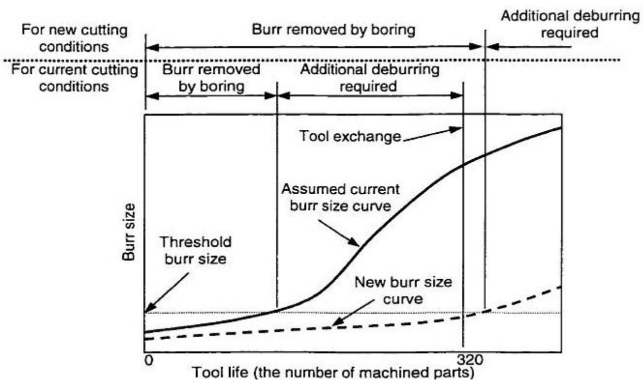


Fig.8 Assumed burr size curve and new burr size curve for proposed cutting condition [6]

Based on Fig.8, the drilling process may be optimized. If the deburring operation needs to be kept, then the tool life can be increased. Conversely, if we eliminate the deburring process, then lowering feed can reduce the burr size [6]. Then trade-offs are possible between reduced drilling process productivity and decreased deburring effort.

4.3Tool Design

Drill geometry influences cutting force, hole accuracy and, therefore, burr formation. The major components of drill geometry are point angle, helix angle, length of chisel edge, and lip relief angle. Recent research shows that the step drill reduces burrs formed during drilling. Step drill bits are designed to enlarge a hole as the bit drills through the workpiece. Each step on the bit is larger in diameter than the step before. By dropping the uncut portion of the work, the step drill minimizes the exit burr, which is formed by the advancing of a drill into a workpiece. This design will also increase the bending deformation during the drilling and prolong cutting without bending to the end of cutting [10].

4.4 Changing Drilling Method

Micro-holes can be generated by alternative manufacturing processes. There has been research about using laser direct drilling to drill hole in PCB. Drilled-hole quality was evaluated and a method was proposed to improve the quality [9]. This method opens new process windows with different environmental, economic, and social implications.

4.5Machine Tool

Energy consumption in a drilling machine tool is due to drilling operations and, non-drilling operations and peripheral equipment. The main approach to address drilling operations is to lower the weight carried by axes with high motion. The main approach to address non-drilling operations is to minimize the energy requirement of peripheral equipment and increase the production rate of the machine tool [7].

5. Conclusions and Future Work

This paper presents issues related to drilling burrs in PCBs. The formation mechanisms for entrance and exit burrs were discussed. So far, most work was done on metallic material, but PCB drilling offers potential for research of multi-layer materials and micro drilling. Drilling Burr Control Charts are an important tool for information technology industries because it helps to understand and predict burr formation. DBCC was used for PCBs and were able to indicate reasonable ranges for drilling operations. Besides DBCC, several approaches were proposed to green drilling processes. Future research is needed to quantify the effect of drill geometry and drill wear on the drilling burr formation, and to improve burr quantification method.

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