Tissue-Homogenized Material for High Reliability PCB Drills

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These days, printed circuit board (PCB) drill tends to be longer and smaller in diameter as the advanced miniaturization and high integration of electric components require smaller holes. In addition, an increasing number of substrates are overlaid for efficient processing. Such drills are easy to be bent and broken, and accordingly the hole position accuracy decreases. To prevent such property degradation, we thoroughly investigated conventional products and discovered that the tissue homogenization of cemented carbide is the key. Through the review of raw materials and optimization of production processes, we succeeded in the development of the high reliability PCB drill material “ZF20A,” thus improving the hole position accuracy and breakage resistance.

Keywords: material for PCB drills, ultrafine-grained cemented carbide, breakage resistance, homogenized alloy structure

1. Introduction

Printed circuit boards (PCBs) are used to secure and wire semiconductor devices and other electronic components. To drill holes in these boards, PCB drills, which are principally made of cemented carbide,*1 are used. Cemented carbide is very hard and highly resistant to wear. It has a high Young's modulus, is highly rigid, and ensures better hole position accuracy.*2

All kinds of PCBs, including those for automobiles and smartphones, are machined with PCB drills. Drill diameters used differ depending on the application. For example, cutting diameters from 0.4 to 0.8 mm are typically used for in-vehicle PCBs, while those of about 0.1 mm are used for boards designed to mount semiconductor packages. The miniaturization and increased levels of integration of electronic components have led to a growing demand for small-diameter drills. Drills with a cutting diameter of 0.05 mm have been commercialized in recent years.(1)

For decades, it has been a general practice to drill through a stack of boards at once for improved machining efficiency. In recent years, the number of overlaid boards has been on an increasing trend. Accordingly, the drill length has also increased. Drills with a cutting diameter of 0.3 mm used to be about 5.0 mm in flute length. Presently, drills 0.3 mm in cutting diameter and even 6.5 mm in flute length are used.

Thinner and longer PCB drills tend to deflect during drilling. This deflection results in degraded hole position accuracy and makes the drill easier to break. Consequently, demand has been high for the development of a material that overcomes the problems of degraded properties and ensures stable machining. To meet this demand, we have conducted a number of studies and succeeded in developing the ultra-hard material ZF20A for high-reliability PCB drills. ZF20A offers improved hole position accuracy and breakage resistance*3 due to its homogenized alloy structure.(2)

2. Problems with Previous Models

Close examination of the cemented carbide materials of the previous models revealed factors that affect the hole position accuracy and breakage resistance of the drills. Table 1 shows the examination results, which indicate that reduced partial wear of the drill cutting edge and coarse tungsten carbide (WC) particles(3) are required to improve drill performance. To overcome these challenges, we identified the causes, explored how to make improvements, and set quantitative targets.

Table 1. Development Guidelines

Purpose	Challenge	Cause	Improvement method	Improvement target
Improved hole position accuracy	Reduce partial wear	Uneven distribution of Co in alloy	[Ingredients] Homogeneous dispersion by using fine Co particles. [Mixing Process] Dispersibility improvement of Co by using a dispersion apparatus.	Co thickness variation (Standard variation: σ) Conventional: $\sigma > 0.07$ New material: $\sigma \leq 0.07$
Improved breakage resistance	Reduce coarse WC particles	Uneven distribution of grain growth retardant	[Ingredients] Homogeneous dispersion by using fine-grain growth retardant. [Mixing Process] Dispersibility improvement of grain growth retardant by using a dispersion apparatus.	Coarse WC particles > 10 μm Conventional: 4 counts / 10 mm² New material: 0 count / 10 mm² 1 to 10 μm Conventional: 11 counts / 10 mm² New material: 0 count / 10 mm²
		Inappropriate sintering temperature	[Sintering Process] Optimisation of sintering temperature	

2-1 Partial wear of the drill cutting edge resulting from uneven Co distribution

In some of drilling tests using PCB drills made of our conventional drill material, hole position accuracy became gradually poor with increasing drilling cycles. This trend was particularly noticeable with small-diameter drills. After testing, close observation with an electron microscope of the drill cutting edges of the PCB drills revealed partial or local wear, as shown in Fig. 1. It is quite probable that the partial wear resulted in increased cutting resistance and degraded hole position accuracy. The structure of cemented carbide is typically made up of WC, which is a hard phase, and cobalt (Co), which is a binder phase. The conventional material is known to have an uneven Co distribution. Regions that contain more Co are softer than other regions. Hence, the wear resistance of such regions is poor. For this reason, it was surmised that partial wear would advance from such a region. Consequently, we aimed to eliminate the uneven Co distribution, achieve a homogeneous structure, and improve hole position accuracy. Moreover, we presumed that a homogeneous structure would be beneficial for improved breakage resistance because partial wear results in increased cutting resistance and reduced tool life before breakage.

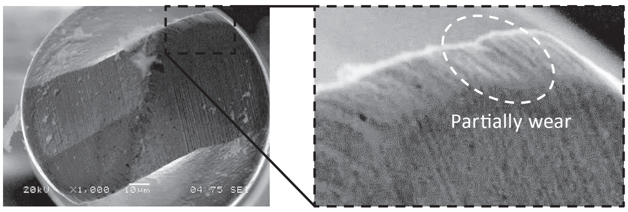

Fig. 1. Partially Wear PCB Drill Cutting Edge

2-2 Coarse WC particles in alloy structure

From various particle sizes of WC ingredient, we select suitable particle sizes for specific applications. The WC ingredient used in cemented carbide for PCB drills is ultrafine-grained, with an average particle size range of 0.1 to 0.5 µm. The reason for this is that the alloy structure becomes finer, hence the alloy's deflective strength*[4] increases, and resultant drills exhibit higher breakage resistance, with decreasing WC particle size. However, simple use of a fine and homogeneous WC ingredient does not translate to a fine structure. The reason is that during the sintering process included in the alloy production process as shown in Fig. 2, part of the WC ingredient turns into coarse WC particles due to Ostwald ripening.*[5] Sintering, in which the material is heated beyond 1,300°C to melt Co, is intended to rearrange (closely pack) WC particles and bind them with Co. In this process, extremely fine WC particles (less than 0.1 µm in particle size) dissolve into Co and then redeposit onto the surfaces of other WC particles (Fig. 3). As a result, coarse WC particles 15 µm in size can occur, far exceeding the average particle size of the original WC ingredient.

Coarse WC particles in the alloy structure are subject to stress concentration during drilling and can be a cause of drill breakage. This is particularly apparent in small diameter drills. Take a drill 0.10 mm in cutting diameter as an example. The web thickness of this drill is between 0.03 and 0.05 mm (Fig. 4). It is quite clear that coarse 0.015 mm WC particles, if present on this drill, can initiate breakage.

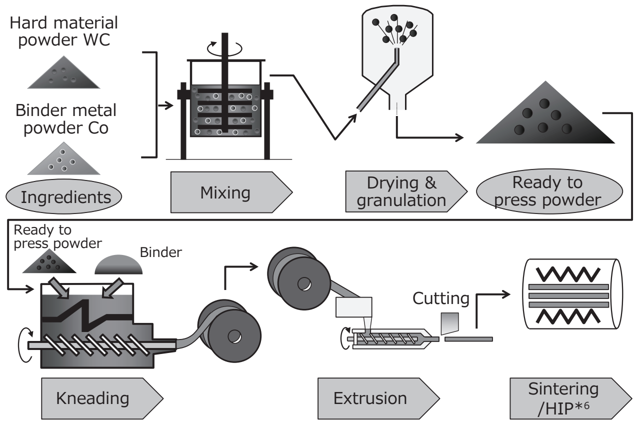

Fig. 2. Manufacturing Process of Cemented Carbide Material for PCB Drills

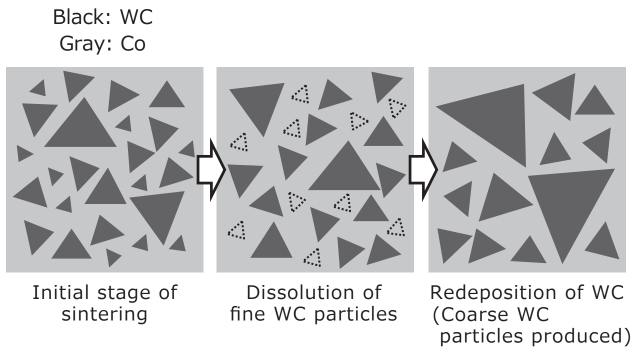

Fig. 3. Coarse WC Particle Production Mechanism

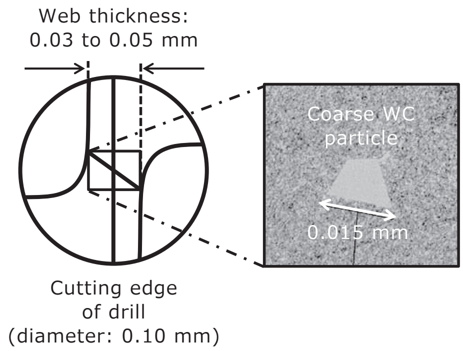

Fig. 4. Cutting Edge of Drill and Coarse WC Particle

2-3 Solutions to challenges

We discovered that a homogeneous alloy structure is required to improve the hole position accuracy and breakage resistance of PCB drills. To achieve a homogeneous alloy structure, it is necessary to control the uneven Co distribution and reduce the number of coarse WC particles. Thus far, efforts to homogenize the structure of ultrafine-grained cemented carbide to the greatest extent possible have not been made. We investigated: 1) selection of cemented carbide ingredients, 2) improvements to the mixing process, and 3) improvements to the sintering process, as shown in Table 1.

3. Features of Materials for High-Reliability PCB Drills

3-1 Selection of cemented carbide ingredients

In the past, development of ultra-hard materials for PCB drills has been promoted with a focus placed on the hard material, WC. To achieve a homogenized alloy structure, none of which has been made available to date, and therefore, the present study reviewed the binder phase, Co, and other additives, as well. Conventionally, Co 0.6 μm or more in average particle size was used. Observation of Co after mixing revealed that the large size of Co prevented WC and Co from being homogeneously dispersed. As a solution, Co in a similar particle size (average particle size: 0.2 to 0.6 μm) to WC was selected for the newly developed material. After mixing, homogeneous dispersion of both particles was verified.

Similarly, what other additives to use was reviewed, including the grain growth retardant used to control Ostwald ripening noticeably seen in ultrafine-grained cemented carbide. The reason for this is likely that its conventional average particle size of over 0.4 μm was inefficient for dispersion, resulting in regional differences in the effect of retarding Ostwald ripening. As a solution, we selected a grain growth retardant of similar particle size (0.2 to 0.4 μm) to WC for improved dispersibility. This ingredient was expected to ensure a homogeneous effect of retarding grain growth and, hence, result in reduced coarse WC particles.

3-2 Improvements to mixing process

The use of a fine Co powder does not always avoid agglomeration, i.e. uneven Co distribution. The process illustrated in Fig. 2 includes mixing in an attritor (ATR).*7 A mixture, or slurry, of powder ingredients and a liquid together with ultra-hard beads are put into a cylindrical container, as shown in Fig. 2. Stirring paddles rotate to mix several different ingredients. Collisions between the beads during stirring helps pulverize and disperse them. The beads used for mixing in the ATR are large, being approximately 5 mm in diameter. Stirring takes time, more than 10 h. In this mixing process, Co agglomerates and becomes large due to its ductility and malleability. Accordingly, after mixing, even a fine Co particle ingredient becomes coarse and unevenly distributed.

We examined the use of a dispersion apparatus for mixing, which is, although inferior to an ATR in pulverization performance, favorable in terms of dispersion. The underlying reason was that mixing by a dispersion apparatus would ensure homogeneous dispersion, being free of reagglomeration of Co. This idea was tested and turned out to produce a better alloy structure than an ATR. The better dispersion capability of the dispersion apparatus was effective in homogeneously dispersing ingredients, thereby ensuring homogeneous Co dispersion, i.e. reducing uneven Co distribution in the alloy, and reducing coarse WC particles due to homogeneous dispersion of the grain growth retardant.

3-3 Improvements to sintering process

In the sintering process, Ostwald ripening facilitates the growth of coarse WC particles. This is particularly observable at higher sintering temperatures. Lower sintering temperatures are effective for reducing coarse WC particles. However, at lower sintering temperatures, molten Co does not readily flow between WC particles and this results in the development of micro-pores (porosity). We looked closely at the sintering process and discovered the optimal sintering conditions for reducing both coarse WC particles and porosity.

3-4 Alloy structure of the newly developed material

Figure 5 compares the alloy structures of the conventional material and the newly developed material based on the above-discussed matters. Black dots in the figure represent Co. The conventional material has an uneven Co distribution, while the newly developed one exhibits a homogeneous Co distribution. To quantitatively evaluate the dispersibility of Co, circular approximation of the black dot regions, representing the Co phase, was conducted and the absolute value and standard variation of the Co phase thickness were determined (Fig. 6). The conventional material is 0.09 in the standard variation of the Co phase thickness. In contrast, the newly developed material has reduced variation, being 0.06 in the standard variation of the Co phase thickness. Thus, the Co phase thickness variation

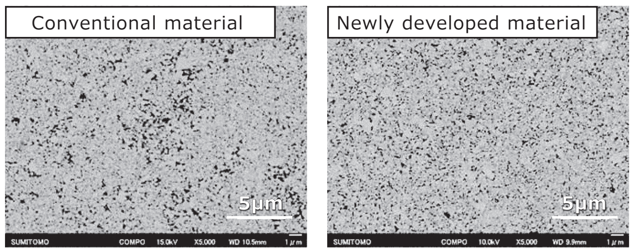

Fig. 5. Comparison of Alloy Structures

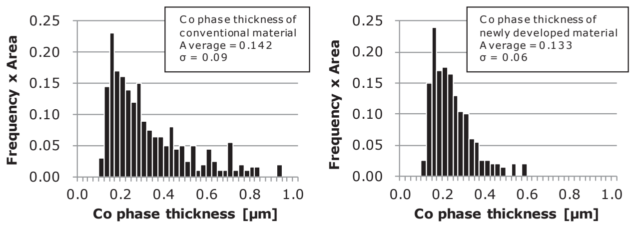

Fig. 6. Comparison of Co Phase Thickness

target set in the initial stage of this study was achieved. Moreover, the newly developed material is free from coarse WC particles, as shown in Fig. 7.

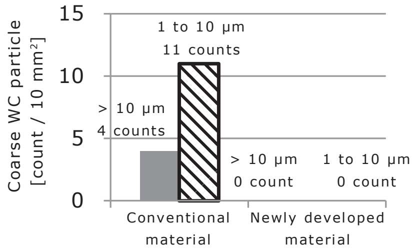

Fig. 7. Comparison of Coarse WC Particle Count

4. Evaluation of Drills

The conventional and newly developed materials, made into PCB drills, were evaluated with regard to PCB drilling. The evaluation consisted of a hole position accuracy test and a breakage test. The test equipment was capable of drilling using six drills simultaneously. A stack of seven PCBs was drilled.

The hole position accuracy test consisted of 3,500 drilling cycles. The maximum distance between the target position and the actual position served as an evaluation index (Fig. 8).

The breakage test used a higher load than usual to the drill, evaluating the drill by the number of drilling cycles performed before breakage and defining it as tool life before breakage. The test was conducted up to 5,500 drilling cycles.

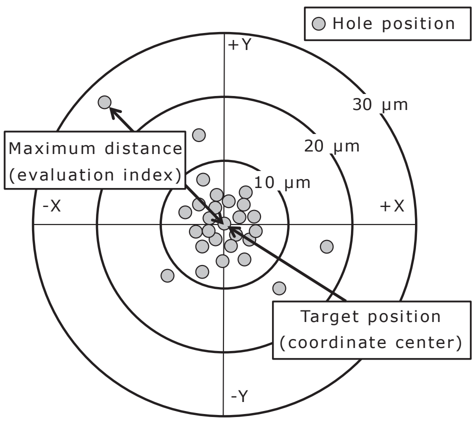

Fig. 8. Hole Position Accuracy Evaluation Method

4-1 Hole position accuracy test

Figure 9 shows the results of the hole position accuracy test. The bar graph represents the average of six samples used for drilling at the same time. The newly developed material exhibited improved hole position accuracy due to less partial wear resulting from uneven Co distribution than the conventional material.

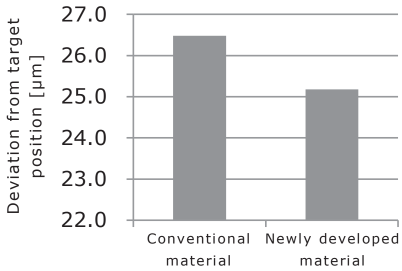

Fig. 9. Comparison of Hole Position Accuracy

4-2 Breakage test

Figure 10 shows the results of the breakage test. The bar graph gives the average of six samples used for drilling. The error bar represents variation. Samples made of the conventional material broke before reaching the limit of 5,500 cycles, while those made of the newly developed material were all free of breakage up to 5,500 cycles, exhibiting stable breakage resistance.

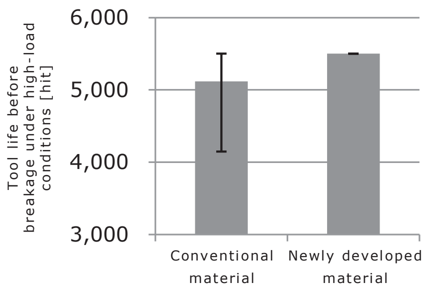

Fig. 10. Comparison of Tool Life before Breakage

5. Conclusion

We succeeded in homogenizing alloy structures to the greatest extent possible by reviewing ingredients and improving the mixing and sintering processes. The resultant PCB drill exhibited higher performance in hole position accuracy and breakage resistance than previous models. These performance improvements are of great significance because poor hole position accuracy and drill breakage in the middle of drilling can lead to a significant loss due to possible defective PCBs and line disruption.

The newly developed ZF20A is highly regarded by our customers for its excellent quality and reliability. The knowledge obtained from the present development project has been rolled out to other products and helped enrich the lineup of our high quality product range. Furthermore, these additionally developed products have also gained a high reputation. We believe that these products will meet demanding requirements in the area of PCB drilling.

Technical Terms

∗1 Cemented carbide: An alloy that contains tungsten carbide (WC) as a hard phase and cobalt (Co) as a binder phase; Cemented carbide is produced by sintering WC and Co powders. The alloy is extremely hard and is widely used to construct cutting tools that need to meet high wear resistance requirements.

∗2 Hole position accuracy: A PCB drill evaluation index; PCB drills are evaluated by the difference between the target and actual hole positions. The greater the difference, the poorer the quality of the drill is. For a stack of several PCBs, the deviation of the hole in the lowest PCB is used for this evaluation.

∗3 Breakage Resistance: Breakage resistance indicates how much a material will resist breaking. This property of PCB drills is evaluated by the number of drilling cycles reached before breakage in an accelerated drilling test conducted under tighter-than-usual conditions.

∗4 Deflective strength: A property value that indicates strength against bending; Deflective strength equals the maximum stress at break reached in a sample under a bending load.

∗5 Ostwald ripening: In an alloy that contains different particle sizes of solid particles, fine particles dissolve into the liquid phase during sintering and redeposit themselves onto other particles of the solid phase during cooling, growing into coarse particles. This phenomenon is known as Ostwald ripening. In cemented carbide, solid- and liquid-phase particles correspond to WC and Co, respectively.

∗6 HIP: Hot isostatic pressing; Sintered alloys occasionally develop micro-pores (porosity). Hot isostatic pressing is a high-temperature, high-pressure process performed to allow Co to fill up the micro-pores. Manufactured materials for PCB drills all undergo the HIP process because porosity is a cause of drill breakage.

∗7 Attritor: A machine designed to mix, pulverize, and disperse several different ingredients; The attritor process comprises stirring with paddles and bead-to-bead collisions.

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