The Trend of Microdrills for Printed Circuit Boards

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Printed circuit boards (PCB), widely used in electronic devices, have been increasingly improving in performance, cost effectiveness and miniaturization. This trend seems to continue for a while, and accordingly, further sophisticated microdrills are also required for precise drilling of PCB. We, at Sumitomo Electric Hardmetal Corp., have produced cemented carbide materials to be used for microdrills for many years, and have commenced mass-production of special materials for composite-type microdrill parts ahead of other manufacturers. Now, we are leading the market as the top manufacturer in this field. In response to diverse needs from users, we are aiming to develop high quality materials and expand the market share even further. In this report, the author describes the development of microdrill material, “Igetalloy,” along with the trend of microdrills.

Keywords: microdrill, printed circuit board, Igetalloy

1. Introduction

Printed circuit boards (PCBs) are widely used in many kinds of electronic devices including audio-visual machinery, household appliances, cameras, PCs, video game machines and vehicles. Due to the trend in highly-efficient, low-cost and downsized electric parts, there is an increasing demand for microdrills that are smaller in diameter and capable of drilling a wider variation of materials.

Sumitomo Electric Hardmetal Corp. has a long history of producing cemented carbide materials for microdrills. In the past several years, we have steadily increased the production of materials designed exclusively for composite microdrill parts to be a leading manufacturer in this field. In this paper, the background of the development of our microdrill material “Igetalloy” is described along with the latest trends of microdrills.

2. The Past and Current Technology in PCB Drilling

2-1 The history of PCBs

In 1936, a laminated type circuit board consisting of an insulation board covered with a metal foil was invented by an Austrian, Paul Eisher. The board was similar to the current PCB in the form[(1)]. During World War II, the laminated type circuit board was used for assembling electronic devices for the U.S. military. In the 1950s, when transistors came into practical use, a one-sided printed wiring board was developed. Since then, the integration of circuits had advanced from the one-sided printed pattern to the double-sided printed pattern, and further to the multilayered circuit. In the late 1980s, 0.4-0.6 mm multilayer PCBs consisting of more than ten layers came into wide use.

In recent years, difficult-to-cut materials have been increasingly used as substrates with higher heat-resistance, and accordingly drilling these materials has become difficult. The shift in the production volume of PCBs in Japan is shown in **Fig. 1**[(2)].

The sharp decrease of the production volume in 2005 is due to the shift of production sites of PCBs from Japan to foreign countries. Now Taiwan and China are the major production bases of PCBs.

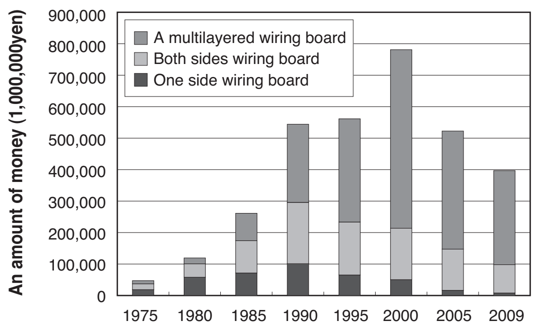

Fig. 1. Shift in the production volume of PCBs in Japan

2-2 Progress of drilling technology

In the years after World War II, drilling was being conducted while operators were visually confirming drilling positions at their desks. In the 1970s, drilling machines equipped with card-type and paper-streamer-type NC control functions were developed in the U.S., and since then the standardization of drills had been promoted[(1)]. As the standardization was led by in the U.S., specifications of drills were measured in inches. The standard specifications of a drill were set to be 1/8 inches (3.175 mm) in drill shank and 1.5 inches (38.1 mm) in length[(3)]. Currently, a drill with a 2 mm shank was developed for high-speed rotary. The figures and names of microdrill parts are introduced in **Fig. 2**[(1)].

The cemented carbide solid type used to be the mainstream of 3.175 mm shank drills, however, in recent years there has been a shift in the trend to the composite type

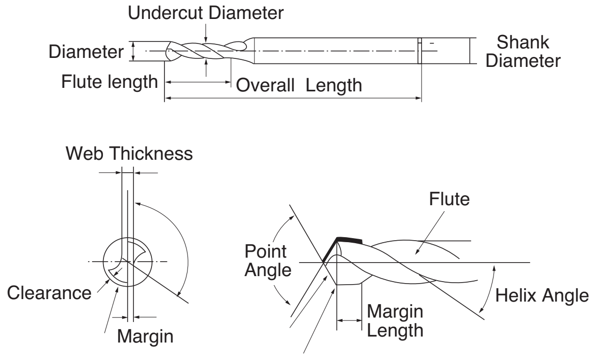

Fig. 2. Figures and names of microdrill parts

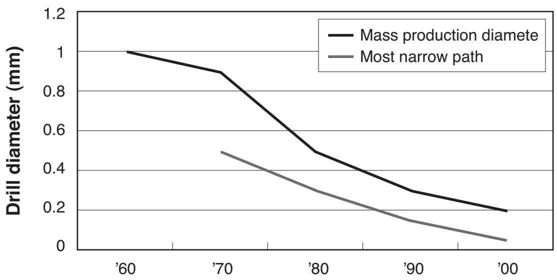

Fig. 3. Shifts in microdrill diameters

which has a cemented carbide grade brazed or inserted to the stainless steel shank. As the composite type drill uses less cemented carbide, it is advantageous to reduce the cost. As the years passed, cemented carbide parts used for the composite type drill have increasingly downsized both in diameter and in length. **Figure 3** shows the shifts in drill diameters.

When the drill diameter becomes smaller, it is necessary to increase the number of spindle revolutions to ensure that the drill goes straight to work pieces. In recent years, drills have developed to demonstrate fast and highly precise operation with multiple axes. An increase in the number of spindle revolutions in practical use is given in **Fig. 4**(3). In response to the movement, development of the cemented carbide is also promoted by using downsized gains of tungsten carbide (WC), the chief ingredient of cemented carbide. Thus far, cemented carbide with 0.2 μm WC grains has been put to practical use. The diameter of the smallest drill now in practical use is only 0.05 mm, which is about a hair width. The web thickness shown in **Fig. 2** is 40-50% of the drill diameter, and therefore the web thickness of the 0.05 mm drill is 0.020-0.025 mm(3). In this case, the drill web contains no more than 100 WC grains, even though these grains are as small as 0.2 μm. To follow the trend towards downsized drills, quality control of the materials used for drills are essential.

3. Required Characteristics for Microdrills

3-1 Drilling quality

For PCB processing, drilling process is important because the quality of drilling greatly affects plating and other subsequent processes, and consequently determines the reliability of the circuit board. The characteristics of drill materials also largely influence the quality of drilling. For PCB drilling is getting more and more difficult every year due to the densification of the PCB, advanced multi-layering, diversification of work piece materials, reduction in the drill diameter and increasing demand for cost saving. Drill materials need to be modified to respond to these changes.

3-2 Troubles in drilling

Troubles caused by the characteristics of drill materials during the drilling process are as follows. The details of the troubles and drill characteristics required to prevent the recurrence of these troubles are described.

① Drill breakage

Breakage of drills can lead to defects of PCBs, resulting in the decrease of work efficiency and cost increase. Therefore, sufficient strength to withstand the load during drilling is necessary, and defects that can decrease the strength of the drill should not be permitted. The relations, according to the WC grain size, between the transverse rupture strength and Co content are shown in **Fig. 5**. Up until 15wt%, as the Co content rises, the strength of cemented carbide increases. In addition, in the relation between the WC grain size and the strength, smaller WC grains show higher strength. The super fine grain WC is used for microdrill materials. Defects that can decrease the

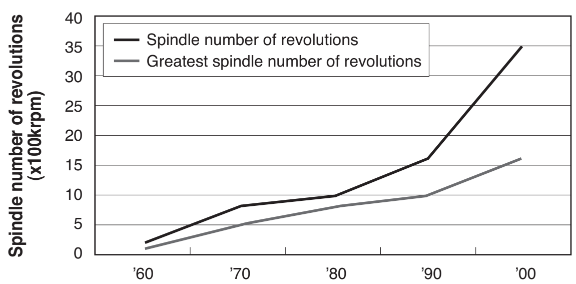

Fig. 4. Increase in the number of spindle revolutions

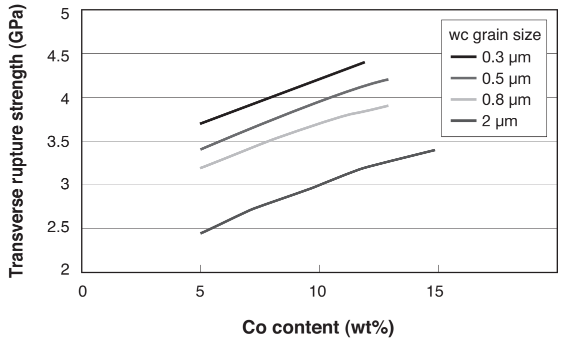

Fig. 5. Relations between Co content and TRS

strength include abnormal microstructure due to the irregular carbon value, wrong size WC grains, Co lakes, pores, alien substances and impurities. These defects must be removed entirely and microdrills must have no defects at all.

② Accuracy of hole positioning

The accuracy of hole positioning is evaluated based on the distance from the standard hole (as shown in **Fig. 6**), and the distance should not be more than 50 μm for accurate positioning. The oscillation of drill spindle and the drill shape greatly influence the accuracy of hole positioning. As for drill materials, their hardness can also influence hole positioning accuracy, and hard materials with high Young's modulus demonstrate accurate hole positioning. **Fig. 7** shows the relation between Co content and Young's modulus, and with little Co content, Young's modulus rises and rigidity increases.

and sharp-edged grades. The relations between Co content and Young's modulus are shown in **Fig. 8**. As Co content decreases, the hardness and wear resistance of cemented carbide increase. The hardness is also affected by the WC grain size; smaller grains provide increased hardness. The grain size decreases when the grade edge is sharp.

The super fine grain materials with small WC grains are superior to other materials when it comes to the transverse rupture strength, hardness, sharpness of the edges, and they are most suitable for microdrills. However, there is a weak point that their fracture toughness is inferior to that of rough grains.

When fracture toughness is insufficient, the grade of a drill is easily chipped. As shown in **Fig. 9**, the hardness and fracture toughness are in the relation of trade-off. Therefore, when drill material is selected, determination of the appropriate point where both requirements meet is important.

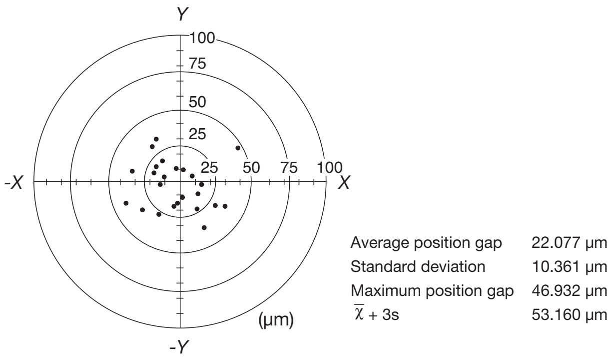

Fig. 6. Measurement of hole positioning accuracy

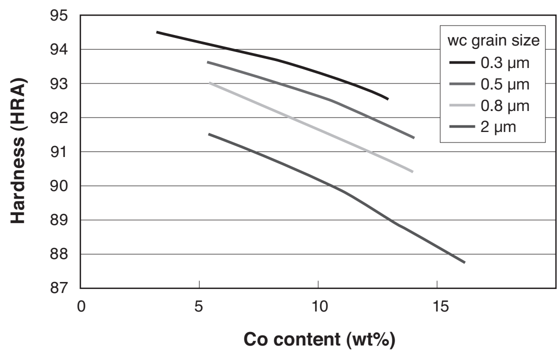

Fig. 8. Relations between Co content and hardness

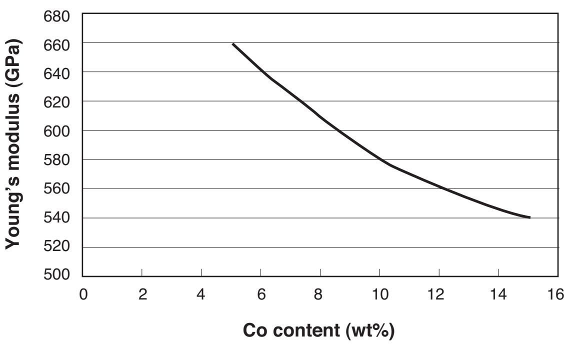

Fig. 7. Relation between Co content and Young's modulus

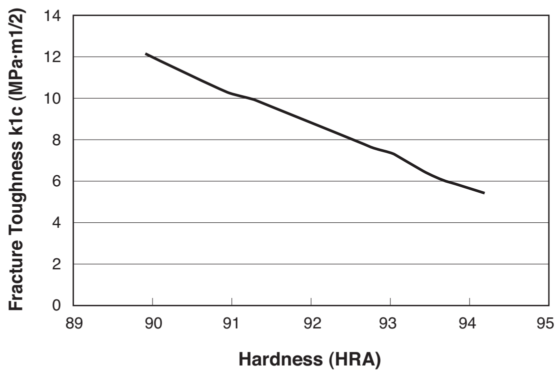

Fig. 9. Relation between hardness and fracture toughness

③ Inner wall coarseness

Inner wall coarseness is a phenomenon that the glass fiber, a material consisting of a PCB, is dug up. When the inner wall is coarse, the PCB is not plated sufficiently and is therefore poor in electricity. When the sharpness of a drill deteriorates, the inner wall becomes coarse. For this reason, the grade of the drill needs to remain sharp without an abrasion or chipping. Drills require wear resistance

④ Smear

Smear is a phenomenon that epoxy resin, a constituent material, is dissolved by the heat generated during drilling. Smear occurs, when the epoxy resin melts to stick on the surface and inner layer of a copper foil. Thus, plating defects result in poor electric conductivity.

The smear outbreak is greatly related to the drill shape and drilling condition, but it is also attributed to the frictional heat generated by a worn grade. Therefore, the drill needs to be hard enough to maintain the grade edge sharp with less abrasion and inner wall coarseness.

3-3 The Characteristics of alloy materials used for microdrills

The alloy characteristics which relate to troubles during the drilling process are shown in **Table 1**; damages to drills and alloy characteristics which relate to the troubles are shown in **Table 2**. Transverse rupture strength, Young's modulus and hardness influence drilling quality, and all the aforementioned characteristics are influenced by the composition (Co content) of the hard metal and WC grain size. Therefore, the appropriate materials need to be selected to avoid both the troubles during drilling and damages to drills.

In recent years, drills which are highly reliable and ensure quality performance are demanded. To obtain high reliability, the lower limit of transverse rupture strength needs to be improved so as to reduce the damages to the drill caused by defects in alloy.

Table 1. Alloy characteristics related to each trouble during drilling

Trouble	Factor	Alloy Characteristic
Break	Strength	Tranverse Rupture Strength
Hole position precision	Rigidity	Young' modulus
Inner wall coarseness	Wear resistance, acute angle degree of the blade	Hardness
Sumiya	Wear resistance	Hardness

Table 2. Alloy characteristics related to drill damage

Damage form	Factor	Alloy Characteristic
Break	Strength	Tranverse Rupture Strength
Tipping	Toughness	Fracture toughness k1c
Abrasion	Wear resistance	Hardness

4. The Shifts in Microdrill Materials

4-1 Progress up to the present

The list of microdrill materials used in the 1980s is shown in **Table 3**. The finest WC grain at that time was 0.5 µm. Subsequently, the mass-production technology of 0.3 µm WC grains was established based on our original direct carbonization technology, which allowed us to develop these materials for microdrills(4). The direct carbonization technology enables us to collect tungsten carbide (WC) without passing through tungsten trioxide (WO3) to metal tungsten (W). The direct carbonization technology is suitable for the production of small WC grains because of the short exposure time to high temperature and cost efficiency. The mass production technology of WC grains as small as 0.2 µm has been established.

Table 3. Microdrill grades of 1980's

Grade	WC Average grain size	T.R.S	Hardness
	(µm)	(GPa)	(HRa)
A1	0.5	4.2	91.4
F1	0.5	4.0	92.4
F0	0.5	3.6	93.6
H1	0.8	3.3	93.2
G1	0.8~2.0	3.1	92.3
K10H	0.9	3.4	92.4

Furthermore, carbonization tantalum (TaC) and carbonization niobium (NbC), which were used as the suppressant of the WC grain growth in those days, are no longer used. TaC easily coheres in alloy, which serves as crack initiation points to lower the strength. In addition, the price of TaC was expensive and unstable in the past. For these reasons, vanadium calcium carbide (VC) and chrome calcium carbide (Cr3C2)(5), which have strong growth suppression effects have replaced TaC.

4-2 Current microdrill materials

The list of current microdrill materials is shown in **Table 4**. For microdrills, 0.3 µm WC has become the mainstream, and 0.2 µm WC was also put into practical use. For the past two decades, the lower limits of transverse rupture strength and hardness have been improved. The comparison of the characteristics and hardness (transverse rupture strength) between old and new materials is shown in **Fig. 10**. The transverse rupture strength and hardness have been improved to get close to the required characteristics to make a reliable drill.

Currently, XF1 is the only one 0.2 µm WC, but the development of new materials is zealously being pushed forward.

Characteristics that are not shown in **Fig. 10**, for example, the number of rough WC grains and the variation of alloy carbon value, have also been improved. These improvements are described in the following chapter.

Table 4. Current microdrill grades

Grade	WC Average grain size	T.R.S	Hardness
	(µm)	(GPa)	(HRa)
XF1	0.2	4.0	93.5
ZF20A	0.3	4.2	93.6
AF1	0.3	4.4	92.5
AF0	0.3	4.1	93.0
AFU	0.3	3.8	93.6
F0	0.5	3.6	93.6
HF0	0.8	3.5	93.0

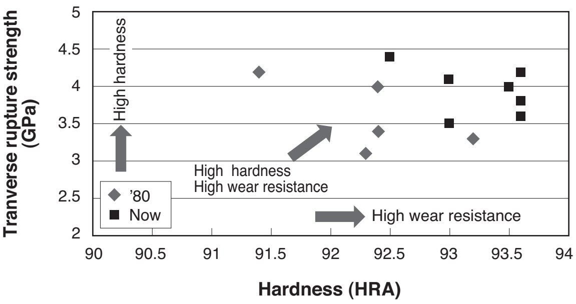

Fig. 10. Development of microdrill materials

5. The Development of the Manufacturing Technique

5-1 Raw material processing

The quantity of carbon is an important factor to control the characteristics of hard metal. When the quantity of carbon is low, an inter-metallic compound called the η aspect is formed, and machine strength falls. Conversely, when the quantity of carbon is high, a free carbon aspect is formed, and the machine strength falls likewise. Decarbonization occurs during sintering, and the quantity of carbon contained in the alloy is reduced from that in the raw materials. The rate of decarbonization greatly depends on the quantity of oxidation contained in WC and Co raw materials. The oxidation easily processes with small WC and Co grains. Therefore, microdrill materials with small WC grains are easily oxidized, and therefore controlling the quantity of carbon is one of the most difficult processes in hard metal processing.

The microstructure of a WC + γ aspect (Co) without a η aspect and an FC aspect at a good level is shown in **Fig. 11**. The microstructure at a good level becomes narrower, as the Co content decreases. With the main material AFU for example, the good level of carbon quantity is achieved in a narrow area of 0.1% or less. With powder raw materials prepared according to the predetermined composition, the quantity of carbon needs to be controlled at even less than 0.1%, because their carbon quantity varies in the subsequent processes. The variation of the carbon quantity in the powder raw material prepared in each lot is controlled at less than 0.03%. This control is carried out by analyzing the collected data about the quantity of oxygen contained in the raw materials (WC, Co, etc.) and the rate of decarbonization, and controlling the temperature and humidity in the factory. These efforts have remarkably improved the precision of carbon quantity control for the drill.

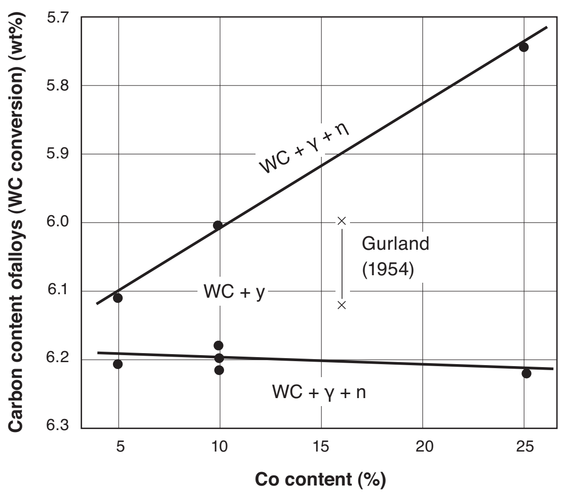

Fig. 11. Microstructure of the WC-Co alloy at good level

5-2 Molding

5-2-1 Manufacturing method

Molding technique of microdrill materials includes two methods: press method and extrusion method. The extrusion method, which is suitable for the composition of drills and shortening cemented carbide parts, is the mainstream. The press method, on the other hand, is used exclusively for manufacturing solid types.

5-2-2 Extrusion method

The extrusion method is suitable for manufacturing long parts that has a uniform cross-sectional shape. The bad point is that it has so much wax added that the shrinkage rate is bigger than that of the press method, and easily forms pores. However, a large quantity of wax covers up WC and Co surfaces, and functions as an antioxidant to prevent decarbonization. Therefore, it has the merit that the quantity of carbon remains stable. The extrusion method is also advantageous in producing cylindrical bars. The press method requires center-less polishing after alloying process. However, the extrusion method can produce cylindrical bars at a comparable level to the press method at the material stage. In the alloy characteristic aspect, the extrusion method realizes the comparable or better characteristics than those by the press method by the optimization of the kneading condition[(6)].

5-3 Sintering

The quantity of carbon in alloy is determined in the sintering process. Although the carbon quantity of prepared powder raw materials can be controlled at a uniform level, that of sintered alloy is not uniform. This variation is caused by the non-uniformity of temperature in a sintering furnace during the temperature rise. The temperature distribution during the dewax process, where the wax coating is removed from products, is especially important. If there is a large gap in temperature distribution in the furnace, the starting point of dewaxing differs according to the position in the furnace. Products dewaxed first absorb wax from the rest of the products, which results in the rise of the carbon quantity. However, it is difficult to equalize the temperature distribution in the furnace at a relatively low temperature range without radiation. The temperature distribution is improved by using high heat conductivity gas as a carrier gas, or by increasing the gas pressure in the furnace to raise the heat conductivity. It is expected that advanced facilities, such as heaters, and heating methods are developed in the future to reduce the variation further.

5-4 Hot Isostatic Pressing

Hot isostatic pressing (HIP) eliminates small pores existing in alloy using high-temperature and high-pressure gas, and thus significantly improves the strength of the material. HIP works effectively for materials with large WC grains, which makes it an indispensable process for microdrills to improve their reliability against breakage.

The HIP pressure used to be set at around 100 MPa, but since the 1990s the use of low pressure has been considered with the spread of Sinter-HIP technology. The HIP pressure presently used is 9.8 MPa or 6 MPa, and the running cost has been reduced. In Sumitomo Electric Hardmetal Corp., further cost reduction is being promoted through the collection of Ar gas and improvement of the charge up.

5-5 Guarantee of quality

The microdrill material is the highest quality product in the Igetalloy product lineup, and its quality must be guaranteed. With the trends in increasingly miniaturized microdrill materials, methods and equipment used for the inspection of these materials need be modified for rigorous inspection.

For the specific gravity measurement, gravimetry in the 0.1 mg unit is necessary. In the case of a ø2 shank material, it is out of the standard with a 1 mg error of weight either in the air or the water. Underwater gravimetry requires scrupulous attention to air bubble adhesion to the samples and temperature changes of the water. For hardness measurement, the Vickers hardness test is conducted with reduced load. The measurement machinery has been improved in the magnetic characteristics to become capable of measuring minute samples. Microstructure defects, such as coarse WC grains and Co lakes, have also been improved by the quality improvement of prepared powder raw materials and sintering methods, which allows us to set tougher standards for microstructure inspection.

For the mass production of microdrill materials, total inspection requires too much time and effort, resulting in increased manufacturing costs. Therefore, we have assessed the variation in each process and have originally established a quality assurance system to perform random inspections efficiently and precisely.

6. The Latest and Highest-Quality Microdrill Materials

Our latest product ZF20A is among the highest quality microdrill materials that have high reliability in drilling. The high reliability of drills refers to the quality of the ally which contains reduced defects as close to zero as possible. With the ZF20A, not only rudimentary defects, such impurity and pores, but also coarse WC grains and Co lakes have reduced to the extremity.

6-1 Reduction of coarse WC grains

It is known that coarse WC grains are formed by Ostwald growth during sintering. Ostwald growth is a phenomenon in which small WC grains dissolve into the fluid phase of Co due to the high temperature of sintering, and precipitate on the surfaces of big WC grains when cooled. Thus the big WC grains grow further to make coarse grains. Ostwald growth occurs easily in alloys containing high carbon. Therefore, we controlled the quantity of carbon at a low level to restrain Ostwald growth. In addition, we used WC of a uniform grain size for the raw material to control dissolution and precipitation in the sintering process.

At the point of preparing the powder raw materials, we controlled the quantity of carbon contained in alloy at a low level and improved the condition for crushing WC grains into a uniform size. In the sintering process, we optimized the heating rate, maximum temperature, its duration time, and the cooling rate.

By these efforts, the size of coarse WC grains, which used to be more than 3 μm, has presently reduced to more than 1 μm in ZF20A.

6-2 Reduction of Co lakes

The formation of Co lakes depends on the homogeneity of prepared powder raw materials, the precision of the press method, and the sintering condition. We have realized a homogeneous microstructure containing no Co lakes as shown in **Photo 1** by using Co, which is loose with little cohesion as a raw material, adding a surface modifier that improves press pressure transmission to the prepared powder, studying better sintering conditions and reducing rough WC grains. Black dots in Photos 1 are Co lakes. ZF20A shows more homogeneous Co distribution and microstructure without rough WC grains than the conventional material.

Transverse rupture strength of ZF20A is shown in **Fig. 12**. As the minimum transverse rupture strength has improved drastically, initial drill breakage does not occur any more and the reliability of drills has remarkably improved.

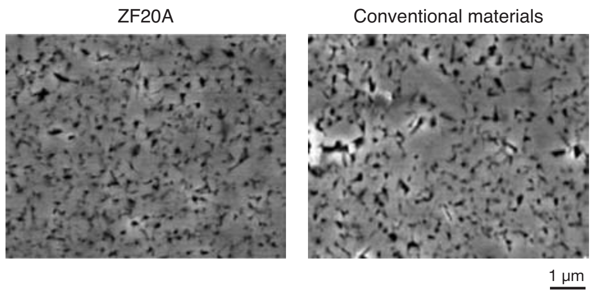

Photo 1. Microstructure of ZF20A

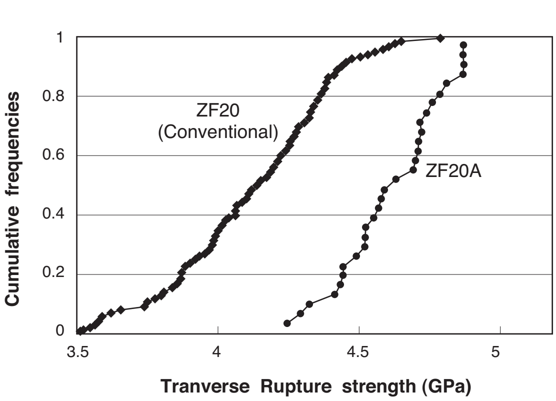

Fig. 12. Transverse rupture strength of ZF20A

7. Challenges to Be Addressed

7-1 The source of raw materials and recycling

The followings are common problems with the whole cemented carbide. The main raw material W is a rare metal, for more than 80% of which the world depends on China. However, depending only on China is dangerous. Sumitomo Electric Hardmetal Corp. and its group companies have promoted the decentralization of supplier. The movement needs to be accelerated further. In addition, from the viewpoint of saving resources, we have collected used cemented carbide products to reuse them as raw material for more than 30 years. The reuse of cemented carbide for super fine grain products is currently limited due to quality issues, however, we must increase the number of the products for which recycled raw materials can be used.

7-2 Development of super infinitesimal grain WC

High quality materials using 0.2 μm WC grains are currently under development. We are working to develop the ZF20A technology further, but there is the problem the growth of WC grains during sintering. We have investigated the optimal sintering condition to avoid the grain growth at a trial level. However, there are scale effects between trials and the actual mass production, and we must find the optimal condition at the actual mass production level immediately.

8. Conclusion

As PCBs have found many applications in the world, it is expected that microdrills will be used continuously for the foreseeable future. The trends in high-density, low-cost boards will go on, and accordingly the development of drills will follow the trends.

We intend to develop and manufacture products that make our customers satisfy without being content with our present status.

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