Featured Topic: Evolution and Future of Cemented Carbide, the Origin of Our Powder Metallurgy Business

"Development of Materials in Response to the Shift from Iron to Multi-material Products"

Nozomi USHIJIMA

Managing Director
General Manager, Advanced Materials Business Unit

1. The Origin of Sumitomo Electric's Powder Metallurgy Business

In the 1920s, the electric wire factory of Sumitomo Electric Industries, Ltd.'s Osaka Works introduced fast wire-drawing equipment in anticipation of a substantial improvement in productivity. However, in the drawing process, the die*[1] through which the copper was pulled was made of steel. The factory faced the problem of reduced die life due to the low wear resistance of steel. The dies could not withstand the high speed of the equipment and quickly wore out. Consequently, the operators needed to stop the equipment frequently for die replacement. The operating rate of the fast equipment remained low, contrary to expectations.

Meanwhile, in 1923, the German light bulb manufacturer Osram GmbH. invented cemented carbide as a composite material in which tungsten carbide (WC) was the hard phase and cobalt (Co) was the binder. This signified the emergence of powder metallurgy products produced by blending WC powders with Co powders and press-molding it, followed by sintering at a high temperature. In 1927, the German steel manufacturer Krupp launched the WIDIA brand of cemented carbides as the first powder metallurgy product on the market.

Noting these technology development trends in Europe, Sumitomo Electric thought that cemented carbide, if used as a drawing die, would solve the problem of the short life of fast-wearing dies. In 1927, the Company organized a research and development project team with the aim of fabricating cemented carbide in-house. The leader of this project team had the admirable qualities of unflagging vitality, an unparalleled ability to take action, and great insight. The team successfully developed carbide dies as early as the following year, 1928, and found a clue to solving the challenge of speeding up the wire drawing equipment. The leader had a sharp eye not simply for the development of cemented carbide as a jig or tool for in-house applications. He also applied the cemented carbide to cutting tools for outside sales. In 1931, the project team launched a range of cutting tools*[2] under the brand Igetalloy, which was the origin of the powder metallurgy of Sumitomo Electric.

The Company subsequently diversified the business into the manufacture and sale of powder metal products and functional material products, which have continued to date. The powder metal products include structural parts for automobiles and consumer electrical appliances, produced by press-molding and sintering iron and aluminum powders, while the functional material products include electrical contacts, electrodes and heat spreaders produced by blending, molding and sintering tungsten and copper or molybdenum and copper powders.

2. History of Carbide Tools Principally for Machining Ferrous Metals

Sumitomo Electric launched its cemented carbide Igetalloy in 1931, which, before the end of World War II, was mainly used to make cutting tools for turning*[3] or milling*[4] ferrous metals into military supplies. After World War II, Igetalloy cutting tools were used to produce automotive parts, steel products, and machine parts. In its early days of development, cemented carbide was intended for dies and other wear-resistant tools. Although these tools have accounted for only a fraction of the business, cutting tools have consistently remained the Company's workhorse. This is true even today, 85 years after the launch of Igetalloy. In the 1980s, when I joined the Company, it was widely discussed that evolving casting and forging techniques would rapidly reduce machining allowance on metal parts and that near-net shape forming*[5] would thrive. Plausible forecasts were also provided that, as a consequence, use of cutting tools would diminish and titanium-based cermet*[6] suitable for removing small allowances would become the mainstream. This speculation turned out to be untrue. Casting and forging techniques did advance; however, the need arose for multifunctional, high-performance and high-quality automobiles and other products, leading to an increase in the number of parts. In addition, parts became increasingly complex in terms of geometry. Consequently, demand grew for machining to form and finish parts after casting or forging. In pursuit of fast and high-efficiency machining, manufacturers providing machining services have come to select predominantly chemical vapor deposition (CVD)- or physical vapor deposition (PVD)-coated grades as carbide tool materials. This trend is growing even today. Meanwhile, use of cermet still remains a major part of the finishing process.

Cubic boron nitride (CBN) grades are often used to machine hardened steel and sintered parts instead of tungsten carbide-based cemented carbide. Even with CBN at the cutting edge, the base is generally made of cemented carbide. Moreover, in recent years, the number of products made of PVD-coated CBN has increased, with coatings—specifically PVD coatings—growing in importance. This is also generally the case with drills, end mills*[7] and other so-called round tools*[8] made of a PVD-coated carbide base material.

Carbide tools have evolved principally for machining ferrous metals, as described above. Nonetheless, the base material is still made predominantly of tungsten carbide, as was the case 80 years ago. No other materials are likely to replace it. Tungsten carbide-cobalt alloys offer superb rigidity and an excellent balance of hardness and toughness. These properties have made carbide tools an industrial product with a very long product life cycle.

3. Emergence of Multi-material Workpieces and Future Developments

Carbide tools have enjoyed growing demand mostly in the machining of ferrous metal parts, as described above. Since the turn of the century, however, their use has been rapidly expanding in non-ferrous metal and nonmetal machining applications. The greatest factor responsible for this is the growing call—more than ever before—for improvements in fuel economy, hence for weight reduction, in the automotive and aircraft sectors. Although the market is expected to expand, formidable environmental and energy constraints exist in these sectors. In the automotive sector, the popularity of hybrid electric vehicles implies an increase in the number of parts due to the increasingly complex internal structures of such vehicles. This naturally leads to increases in vehicle weight. To offset the extra weight, demand is growing for a shift towards lighter materials.

While on the one hand, ferrous materials have improved to meet weight reduction needs, as seen with ultra-high-tensile steel*[9] and hot stamping materials;*[10] on the other hand, use of aluminum to construct powertrain*[11]-related parts is rapidly increasing. Moreover, other development themes have become more concrete, such as transmission cases constructed of magnesium, intake manifolds and fuel tanks made of plastic and carbon fiber reinforced plastic (CFRP) propeller shafts. Steel has a specific gravity of 7.8 (g/cm^3) in comparison with 2.7 for aluminum, 1.8 for magnesium, and 1.2-1.5 for CFRP. The trend of shifting from heavier to lighter materials seems to continue to grow. In automotive applications, potential demand for these materials is exceptionally high. How flame-resistant magnesium, the development of which Sumitomo Electric is working on, and thermoplastic CFRP, which in a sense is value-engineered aircraft CFRP, will be employed for automotive applications is currently a focus of attention. These materials are expected to face fierce competition in terms of quality, performance, cost, and recyclability. This trend is said to be observed not only in Japan, but also in Germany and the United States. Cutting tools are expected to machine more and more multi-material workpieces on a global scale.

Similarly, in the aircraft sector, there has been a remarkable evolution of weight reduction solutions, including increased use of CFRP to construct hulls. Moreover, research and development is under way to use ceramic matrix composites (CMCs)*[12] of silicon nitride ceramics to replace Inconel and other nickel alloys, which have a specific gravity three times higher than that of CMCs.

4. Tool Materials and Design Adapted to a Multi-material Approach

Demand still remains high for tool materials intended to machine ferrous materials such as steel, cast iron, stainless steel, sintered parts, and heat-resistant alloys. Accordingly, for the development of Sumitomo Electric's tool materials, we need to improve the conventional lines of tool materials to enable faster and more efficient cutting of ferrous materials. Additionally, it is quite important to enhance our material and design development efforts in line with the multi-material trend. Needs arising from the shift towards both nonferrous metal and nonmetallic workpieces are expected to be met mostly by polycrystalline, single-crystal, and other diamond grades produced by high-temperature, high-pressure techniques. Meanwhile, it is difficult for conventional diamond tools to cut precision molds made of cemented carbide or toughened-ceramic parts. For these applications, among other tool diamonds, binderless nano-polycrystalline diamonds are expected to be used in a wider range of applications, because they are harder and stronger than single-crystal diamonds and free of anisotropy, that is, a drawback of single-crystal diamonds in terms of usage.

However, we need to meet the challenge that both PCD and single-crystal diamond tools are subject to substantial design constraints. Polycrystalline diamonds are usually cut out of a sintered disc. Therefore, as with single-crystal diamonds, they are limited in that they only form a straight section of the cutting edge. This implies that round tools, produced by providing a diamond-like carbon or diamond coating on a carbide base material, seem to continue to be used more often in applications including drilling into CFRP. If it becomes possible to produce high-temperature, high-pressure-molded blanks with three-dimensional features with ease, diamonds and CBN tools will improve in design flexibility, enabling them to be used in a far wider range of applications.

Over the last several years, three-dimensionally designed tools have been gradually appearing on the market, being produced by injection molding or metal 3D printing. It is presently difficult to apply these technologies to diamonds or CBN. However, injection molding is used to form carbide inserts and drills, and metal 3D printers are used to produce steel-made holders and cutters. These technologies are expected to play an important role as a design development tool.

Technical Terms

∗1 Die: A tool with a conical hole for metal wire production; A metal wire is passed through this hole and drawn to reduce its diameter.

∗2 Cutting tool: Consisting of a cutting edge on one end of a shank or body, cutting tools are set on a lathe or a boring, planing, shaping, or slotting machine for cutting.

∗3 Turning: A method of achieving a required shape and accuracy by applying a cutting tool to a rotating workpiece and traveling the cutting tool.

∗4 Milling: Cutting performed to provide a flat or curved surface on a workpiece by means of a rotating tool provided with a number of cutting edges. (milling machine, end mill, etc.)

∗5 Near-net shape forming: A forming method used to achieve a geometry close to the final product so as to reduce the time and cost required for cutting or other removal of material.

∗6 Cermet: The term "cermet" is a portmanteau word derived from ceramic and metal. Cermet is a composite material produced by blending and sintering a titanium-based hard compound and a metal binder.

∗7 End mill: A tool with a shank and with cutting edges around the tool and on the end face; An end mill is used to cut a flat surface or wall surface by rotating and traveling the tool.

∗8 Round tool: A drill, end mill or other tool that rotates and machines the workpiece.

∗9 Ultra-high-tensile steel: Steel with tensile strength of not less than 1000 MPa is referred to as ultra-high-tensile steel.

∗10 Hot stamping material: Hot stamping materials usually refer to steel doped with Mn or B; Hot stamping is a manufacturing method used to produce high-strength stamped parts by die-molding a heated and softened steel sheet followed by cooling/quenching the molded sheet in the dies as it is.

∗11 Powertrain: A series of devices designed to transmit energy from an engine to drive wheels; A powertrain consists of an engine, transmission, driveshaft, etc.

∗12 CMC: Lightweight, heat-resistant and high-strength ceramic matrix composite; Research and development is under way to use CMC as a material for structural members for aerospace engines.