History of Development of Cemented Carbides and Cermet

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Cemented carbide was first commercialized by our company in 1928 for use in wire drawing dies. It has since been developed as a base material for cutting tools. First, titanium carbide was added to make the tools suitable for steel cutting, and then the ACE layer technology was developed in order to toughen the cemented carbide substrate. Zirconium was added to cemented carbide substrates in response to user requests for efficient machining. Meanwhile, cermet, base material that consists of a hard titanium phase and was originally created for use in jet engines, was developed for cutting tools because of their low reactivity with steel and fine cutting surface. Although toughness was an issue with cermet, it was solved by nitrogen doping. The subsequently developed surface hardening technology further improved their toughness and wear resistance, and thereby cutting performance. This paper details the history of the development of Igetalloy cemented carbide and cermet.

Keywords: Igetalloy, cemented carbide, cermet, cutting tool

1. Introduction

The performance of cutting tool materials has been continuously enhanced in response to users' needs for higher cutting speed. The first high-speed steel appeared on the market in the beginning of the 1900s. At present, cemented carbide accounts for the majority of cutting tool material because it can cut workpieces at a higher speed than high-speed steel as shown in Fig. 1. In the latter half of the 1970s, cemented carbide tools coated with alumina or titanium compound were developed and they enabled a far higher cutting speed.

Meanwhile, cermet is a composite material consisting mainly of a hard titanium phase. Although cermet was originally developed for use as a jet engine material, it has evolved as a cutting tool material separately from other tool materials because of its low reactivity with steel and fine cutting surface.

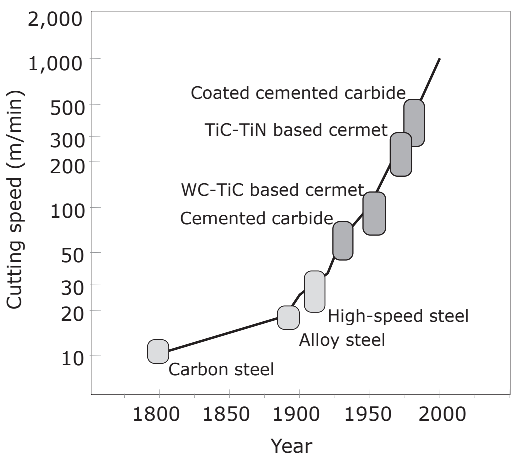


Fig. 1. Development of Cutting Tool Material and Cutting Speed with Time

The percentages of currently used cutting tool materials (indexable inserts) are shown in Fig. 2.

This paper describes the development and history of cemented carbide and cermet.

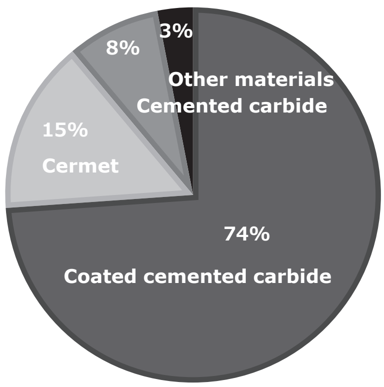


Fig. 2. Percentages of Indexable Insert Materials

2. History of Cemented Carbides

Cemented carbide is a composite material consisting of tungsten carbide (WC) as the hard phase and cobalt (Co) as the binder phase. Cemented carbide was developed by Osram Lamp Works in 1923 and placed on the market by Krupp AG in Germany in 1927 as a cutting tool under the tradename of "WIDIA." Cemented carbide innovated cutting work by achieving steel cutting speeds of 100 to 150 m/min, approximately four times the cutting speeds of high-speed steel (20 to 40 m/min).

In 1928, Sumitomo Electric Industries, Ltd. succeeded in the test production of a cemented carbide wire drawing die shown in Photo 1, which was the first Igetalloy product. In 1931, the company commercialized the cemented carbide cutting tool shown in Photo 2. Since then, the company has continuously improved the performance of cemented carbide to meet the needs of the times.

Photo 1. Cemented Carbide Wire Drawing Die

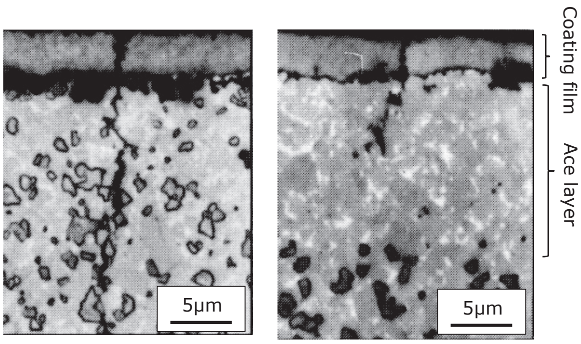
Photo 2. Cemented Carbide Cutting Tools

3. Development of Igetalloy Cemented Carbides

With the aim of enhancing steel cutting efficiency, Sumitomo Electric promoted the research and development of titanium carbide (TiC)-added cemented carbide. The life of cemented carbide at that time depended on the crater wear attributable to scratching of the rake face by chips, and the research and development engineers in charge were confronted with the challenge of extending tool life. The company reduced crater wear dramatically by adding TiC to cemented carbide, and commercialized TiC-added cemented carbide in 1936. Since then, the company has promoted research and development on the addition of tantalum carbide (TaC), molybdenum carbide (Mo_2C), chromium carbide (Cr_3C_2), vanadium carbide (VC), and other compounds to cemented carbide. Irie et al. carried out a detailed study on the crater wear-generating mechanism. As a result, they further enhanced the performance of cemented carbide.[(1)]

To meet the diversifying user needs in those days, the company continued to commercialize a wide variety of cutting tool materials. As a result, the number of types of cemented carbide increased from four in the 1930s, S1 and S2 for steel and G1 and G2 for cast iron, to 26 in 1965. Although this was a result of the company's effort to meet users' needs for higher performance cutting tool materials, an increase in the types of tool material caused users to wonder which tool material to choose. To eliminate such inconvenience for users, the company started to develop a cutting tool material that would be able to fulfill a wide range of cutting conditions. The first product was G10E for cutting cast iron. The then available cast iron cutting tool materials were composed simply of WC-Co. In contrast, G10E was an epoch-making material made by adding a minute amount of TaC to cemented carbide. It complied with all requirements of Japanese Industrial Standards (JIS) for grade K10 and grade K20 materials.*1 G10E is still one of the popular cast iron cutting tool materials even in 2015.[(2)] The company also applied the concept of unifying materials as steel cutting tool materials, and released ST20E in 1966. To make ST20E comply with the performance required of JIS grade P10 and grade P20 materials,*2 the company had to ensure that two conflicting properties required of cutting tool materials, wear resistance (including crater wear resistance) and chipping resistance, were compatible with each other. A special alloy structure was developed for ST20E to make the above two conflicting properties compatible with each other. In particular, the complex carbonitride of (Ti, Ta, W) C phase was refined and the particle size of WC, the main hard phase, was increased.[(3)]

In 1976, the company released Ace Coat AC720, a higher wear resistance material coated with a TiC ceramic film for steel turning applications. In addition to a ceramic coating that improved the wear resistance of the material dramatically, a new technology called "Ace Layer Technology" was used for the cemented carbide substrate of AC720. A WC-TiC-Co alloy (grade P) with a hard TiC phase added was used for tool materials for steel turning applications in order to maintain their wear resistance for a certain period of time even after the coated films were worn out. However, the chipping resistance of this alloy was lower than that of WC-Co alloy (grade K). A super-hard ceramic film covering the outermost surface of the WC-TiC-Co alloy further degraded its chipping resistance. To overcome this disadvantage, the company used its unique sintering technology to develop a cemented carbide substrate with an inclined structure consisting of a grade K cemented carbide layer to a depth of several µm from the outer surface and a grade P cemented carbide layer immediately beneath the grade K layer. This inclined structure is called the Ace layer, and was used for the ceramic-coated substrate of the AC720. The growth of cracks on substrates with and without an Ace layer is shown in Fig. 3. This figure verifies that the Ace layer prevented the growth of cracks. The Ace layer technology has become a standard technology for the development of coated substrates for steel turning tools. This epoch-making technology is used by Sumitomo Electric and its competing companies when developing their most advanced materials.[(4)]

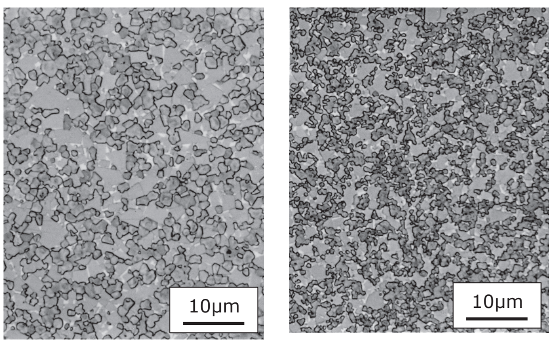


Cemented carbide base material without Ace layer

Cemented carbide base material with Ace layer

Fig. 3. Progress of Cracks in Cemented Carbides with and without Ace Layer

In 1984, Sumitomo Electric developed a nitrogen-containing cemented carbide A30N as a material for milling cutters. When a nitrogen-containing component (TiWTaCN) is added to cemented carbide, the hard nitrogen-containing component is refined and disperses as shown in Fig. 4 and increases the Transverse-Rupture Strength (TRS)*3 of cemented carbide when compared with cemented carbide containing no nitrogen. At the initial stage of the development of A30N, nitrogen decomposed and a special kind of layer was formed on the surface of this cemented carbide. The company optimized the sintering conditions and composition of this alloy to prevent the formation of such a special kind of layer. Enhancing the dispersion effect of complex carbonitride by adding nitrogen also made the wear resistance and chipping resistance of A30N compatible with each other.[(5)]



Cemented carbide with no nitrogen added

Cemented carbide with nitrogen added (A30N)

Fig. 4. Structural Comparison between Cemented Carbides with and without Nitrogen

A Zr-added substrate was developed in 1994 as a material for steel turning, AC2000. Users' needs for turning steel at higher speeds and higher feed rates were increasing at that time. The problem to be solved before meeting the above users' needs was how to minimize the plastic deformation of cutting tool edges. Since the temperature of cutting tool edges reaches approximately 1000°C, it is crucial to prevent the cemented carbide substrate's original hardness and strength from degrading even after it is heated to such a high temperature. Before AC2000 was developed, TiC or TiN having low reactivity with steel had been added to coated substrates for steel turnings. In the development of AC2000, we focused on the use of ZrC and ZrN in place of TiC and TiN as additive compounds. When ZrC or ZrN is added to cemented carbide, a minute amount of solid Zr is dissolved in Co, which is a metallic binder phase, thereby accelerating the solution of solid to some extent. As a result, cemented carbide maintains high hardness at high temperatures as shown in Fig. 5. Co segregation at the Co grain boundary is also suppressed, improving the high-temperature strength of cemented carbide as shown in Fig. 6. However, Zr tends to react readily with oxygen to form ZrO_2. To provide AC2000 with excellent plastic deformation resistance, we optimized the additive amount of Zr and improved our sintering technology.[(6)] Addition of Zr to cemented carbide was also applied to the development of AC820P, the material that was developed subsequent to AC2000.

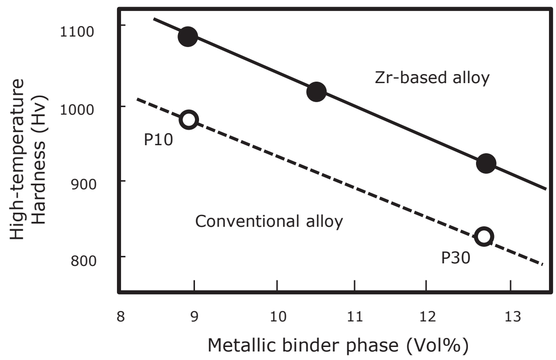


Fig. 5. High-Temperature Hardness of Cemented Carbide Containing Zr

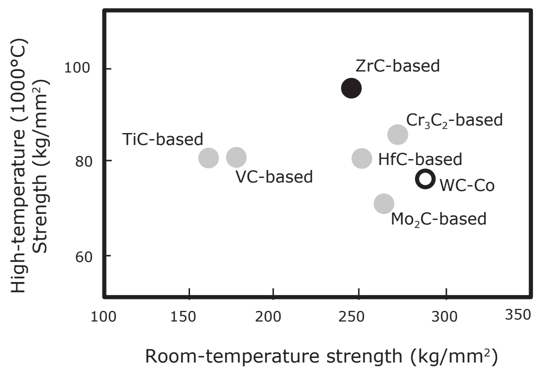


Fig. 6. High-Temperature Strength of Cemented Carbide Containing Zr

4. History of Cermet

Less than a decade after cemented carbide was invented in 1923, a hard material consisting mainly of a carbide other than WC was developed. In 1930, a TaC-Ni alloy was sold on the US market under the tradename of Ramet. In the following year, a TiC-Mo_2C-Ni-Cr alloy was commercialized in Austria under the tradename of Titanit. However, these materials were not widely used since they were inferior to cemented carbide in toughness. With the progress of the development of jet engine materials after World War II, research and development on cermet (ceramic + metal), a composite material composed of ceramic and metallic materials, was actively promoted in and after 1950. Although cermet was not used as a jet engine material because of insufficient toughness, the research and development of cermet for cutting tool applications continued. Cermet has evolved as a finishing tool material since it provides fine cutting owing to its extremely low reactivity with steel.

5. Development of Igetalloy Cermet

It is said that the world's first cermet for cutting tool applications appeared on the market in 1956. Humenik et al. of Ford Motor Company in the US were the first in the world to improve the wettability of the hard phase and metallic binder phase of a TiC-Ni alloy by adding Mo. Sumitomo Electric signed a technology partnership agreement with Ford in the US in 1972, and developed TiC-Mo-Ni alloys called Ticut S, 2S, and 3S. However, these materials had problems with thermal fatigue toughness and plastic deformation. In addition, the inferior brazability of cermet was inconvenient in those days where most cutting tools were made by brazing.*4 These disadvantages are considered to have prevented the widespread use of cermet.

Nitrogen (N)-added cermet T12A was developed in 1976 to improve significantly the disadvantageous characteristics of cermet. Compared with N-free cermet, T12A had far higher toughness. As shown in Fig. 7, the hard phase particle size of T12A containing N was reduced to approximately 1 µm from the conventional cermet containing no N (Ticut S), which was 4 to 5 µm. The characteristics of these two types of alloys are shown in Table 1. As this table shows, T12A was superior to Ticut S in TRS and hardness. T12A also had high thermal diffusivity, thereby dramatically improving thermal fatigue toughness over Ticut S. An example of cutting a workpiece with T12A is shown in Fig. 8. This figure shows that T12A exhibited an overwhelmingly longer tool life than a cermet cutting tool made by a competitor.[7] T12A received a high reputation as an epoch-making cermet cutting tool material. The popularity of T12A was also supported by the change in mainstream usage of cutting tools from brazed tools to indexable inserts.

Table 1. Alloy Characteristics of T12A and Ticut S

	Hardness (HRA)	TRS (kg/mm^2)	Thermal diffusivity (cm^2/sec)
T12A	92.1	165	0.084
Ticut S	91.6	130	0.063

Workpiece: connecting rod
Workpiece material: S55C
Cutting condition: V = 114 m/min; d = 0.2 mm; f = 0.12 mm/rev.

Tool material	Number of cut workpieces (pieces/corner)
T12A	1900
Cermet made by competitor	300

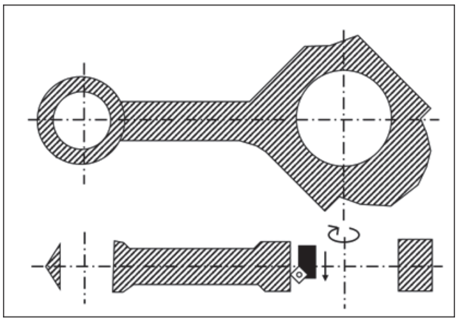


Fig. 8. Example of Cutting by T12A

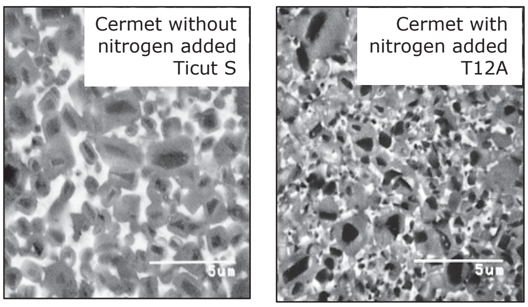


Fig. 7. Structural Comparison between Cermets with and without Nitrogen Added

Sumitomo Electric continued to develop cermet with nitrogen added. In 1988, the company launched New Ticut T 130A whose hard phase had finer particles than those of T12A. The nitrogen content of New Ticut T130A was increased to 6.0 wt%, which was more than two times that of T12A (2.5 wt%). An alloy containing as much as 6.0 wt% of nitrogen produced many pores (blowholes) inside, thereby degrading strength. To overcome this shortcoming of the alloy, the company made full use of atmospheric sintering technology to succeed in developing a defect-free cermet containing a high percentage of nitrogen. The structure of nitrogen-added cermet T130A was further refined from T12A. As a result, T130A enhanced remarkably its TRS and was reputed as an alloy that was highly reliable in chipping resistance.[8]

After that, Sumitomo Electric carried out research on the optimization of the composition and structure of cermet, and commercialized surface-hardened cermet T220A in 1993. This cermet consisted of an inclined structure in which the amount of metallic binder phases was minimized on the surface and gradually increased in proportion to the thickness of the alloy. The inclined structure made it possible for the alloy to simultaneously fulfill two functions: high wear resistance on the surface and high toughness in the interior. Inclining the metallic binder phase generated compressive residual stress on the surface of the alloy because of a difference in thermal expansion coefficient between the surface and interior. This compressive residual stress suppressed cracking of the alloy that would lead to chipping of the cutting tool. The case hardened cermet technology was also used for T1200A and T1500A, which were commercialized in 1997 and in 2010, respectively.

6. Conclusions

This paper has discussed the development of Igetalloy cemented carbide and cermet with a focus on their use as cutting tool materials. Sumitomo Electric began to develop Igetalloy cemented carbide in 1928. Since then, these alloys have been improved continuously and the performance of the latest alloy is far superior to that developed in 1928. Sumitomo Electric's current lineup of Igetalloy cutting tool materials includes coated cemented carbide AC820P and cermet T1500A for steel turning applications and ACP200 for steel milling applications. These cutting tool materials were developed based on various technologies that Sumitomo Electric has accumulated over the years, and are contributing to improved productivity for users. Coated tools are used widely at present. The cutting performance of a coated cemented carbide tool and cermet tool depends largely on the compatibility of the coating film with the substrate. Sumitomo Electric will continue to develop new coating films and new cemented carbide/cermet substrates. Through providing users with cutting tool materials that meet the needs of the times, we will contribute to the development of industries both in Japan and overseas.

Technical Terms

*1 Grades K10 and K20: Classification of cemented carbide materials for cast iron cutting tools (gray cast iron, spherical graphite cast iron, and malleable cast iron)

*2 Grades P10 and P20: Classification of cemented carbide material for steel and cast steel (excepting austenitic stainless steel) cutting tools

*3 Transverse-Rupture Strength (TRS): Maximum bending stress measured in three-point bending test

*4 Brazed cutting tool: Cutting tool made by brazing a tip to a tool body

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