Development of Cemented Carbide Tool of Reduced Rare Metal Usage

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Hard materials used for cutting tools include cemented carbides (WC-Co) and cermets (TiCN-Co/Ni). Tungsten, the main component of cemented carbides, is subject to supply risks. On the other hand, titanium, the main component of cermets, is at a much lower risk than tungsten. This work evaluates a composite structure of cemented carbide and cermet to reduce tungsten usage while maintaining the performance of the cutting tool. Composite structural materials are generally prone to cracking, deformation and breakage caused by the difference in shrinkage characteristics during sintering; the difference in the coefficient of thermal expansion; and the transfer (migration) of binder phase in the liquid state. We succeeded in producing a composite structural tool that shows cutting performance equivalent to cemented carbide tools in terms of wear and breakage resistance.

Keywords: cemented carbide, cermet, cutting tool, resource saving of tungsten, rare metal

1. Introduction

Cemented carbides, including coated cemented carbides, account for 75% of the cutting tools market because of their features such as high hardness, toughness, and the responsiveness to iron, through the use of tungsten carbide for their main hard phases and cobalt for their bonding metals. The consumption of tungsten continues to increase as the amount of carbide tool production increases with the expansion of markets in developing countries. On the other hand, as **Fig. 1** illustrates, tungsten is an eccentrically located material and China accounts for 60% of the reserves and 76% of the production for the world market.

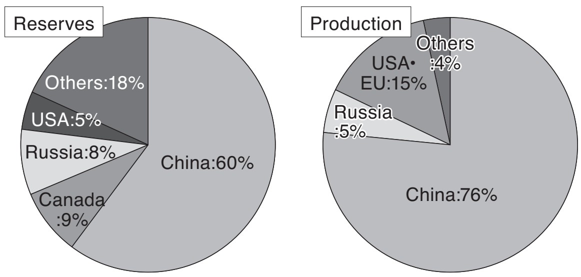

Fig. 1. Reserves and production of tungsten

Similar to regulations on rare earth, the Chinese government has been limiting the supply of tungsten and raising customs on it, regarding tungsten as a rare metal. Furthermore, China is also starting bans on the export of tungsten in the form of ore, and shifting its form of shipping toward high-value-added products such as ammonium paratungstate, an intermediate material of tungsten carbide powder; tungsten carbide powder; or cemented carbides. All of these factors account for higher prices and the high supply risk of tungsten, as **Fig. 2** illustrates.

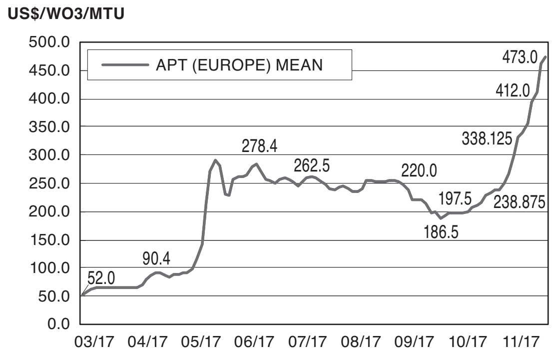

Fig. 2. Change in APT price

Tungsten is a base material of cutting tools that bolster the broad industries of automobiles, construction equipment, steel, airplanes, and electronic components. As such, the Japanese government has started a national project to reduce the use of and develop the substitution of rare metals such as tungsten, indium, and dysprosium. Sumitomo Electric Industries, Ltd. participates in the government's project, Rare Metal Substitute Materials Development Project (led by Ministry of Economy, Trade and Industry in 2007 and by New Energy and Industrial Technology Development Organization (NEDO) from 2008 through 2011). We have succeeded in achieving the same cutting performance as cemented carbide tools with 20% reduced tungsten usage, which is higher than the intermediate reduction goal of 15%.

This article reports on the development and performance of the cutting tool with reduced tungsten.

2. Development Target

Typical hard materials for cutting tools other than cemented carbide include cermet, of which the main component is titanium. Titanium has a much lower risk of supply than tungsten in terms of its reserves and distribution. **Table 1** shows the properties of cermet compared with cemented carbides, and **Photo 1** shows the microstructure.

Table 1. Comparison of properties

Properties		Cemented carbide	Cermet
Thermal conductivity	w/m • °C	105	33
Thermal expansion	$\times10^{-6}$ / °C	4.5	7.5
Toughness	MPa • $m^{1/2}$	8	6.5
Young's modulus	GPa	620	420
Density	g / cm^3	15.0	6.1
Price	yen / cm^3	69	26

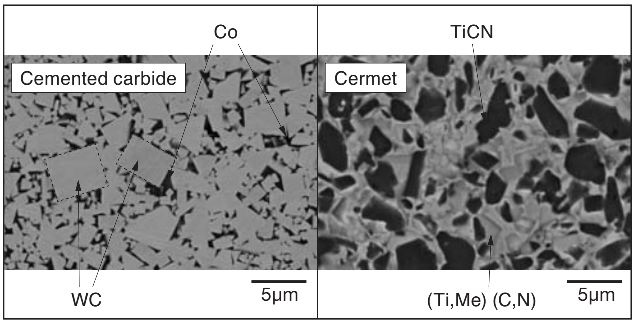

Photo 1. Micro structure of SEM

The thermal properties of cermet (including thermal conductivity and thermal expansion) are, however, inferior to those of cemented carbides. As a result, the cutting performance of cermet in high temperatures that are likely to be led by high speed and high performance machining is inferior to that of cemented carbides. In addition, although cermets in general have high hardness, their fracture toughness is low, and the range of cermet's suitable cutting conditions is very limited. It was difficult to find a material that can substitute cemented carbides in all areas. In our attempt to find a substitution material for cemented carbides, we promoted the development of cutting tools with reduced tungsten usage while maintaining the performance comparable with that of cemented carbides.

We set our target reduction rates of tungsten usage to 15% at the intermediate point in 2009, which was the time frame set by the Ministry of Economy, Trade and Industry when we started participating in this project, and to 30% at the final point in 2011. These targets were intended to enable accepting the demand increment in 2011 even when the tungsten supply would not increase from 2007, the starting year of this project of the Japanese government.

3. Concept of Tungsten Reduction Cutting Tool

This article evaluates a composite structure of cemented carbide and cermet designed to reduce tungsten usage while maintaining the performance of the cutting tool. The tool's cutting edge was made of cemented carbide in order to maintain wear and breakage resistance, and the other parts were made of cermet containing increased tungsten that has similar sintering temperatures and shrinkage properties, as well as the strength to handle the cutting pressure.

Forming the 3D chip breaker, which is vital to the cutting process, was important in the manufacturing of the composite cutting tool of cemented carbide and cermet. **Photo 2** shows the 3D chip breaker, which has a complex concave-convex shape on the surface of the cutting tool. This shape prevents any bad influence of long chips on automatic operation and the work material because the shape decouples chips.

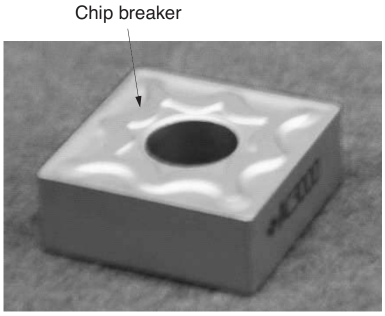

Photo 2. Cutting tool of cemented carbide

We tried various methods of producing a composite structure, such as the methods of sintered compact joining, pressure sintering such as hot press, and injection molding; however, we were facing some problems in the ease of mass production and in cost. We reached a conclusion that the sintering method of composite green compact has an advantage in terms of cost and ease of mass production because this method is already in conventional use; therefore, we proceeded with development by employing this method.

4. Problems in Developing the Cutting Tool of Reduced Tungsten

Cemented carbide tools are manufactured by pressing powders into given shapes and sintering them in high temperatures of around 1400°C. During sintering, cemented carbide in general is densified along with linear shrinkage of approx. 18%, which is made possible as melted cobalt fills the gaps between each tungsten carbide. When a composite is manufactured from heterogeneous materials with high shrinkage ratios, the composite is prone to delamination and deformation, as shown in **Photo 3**. In addition, properties change during sintering through the migration of bonding metal between the heterogeneous materials, as shown in **Photo 4**.

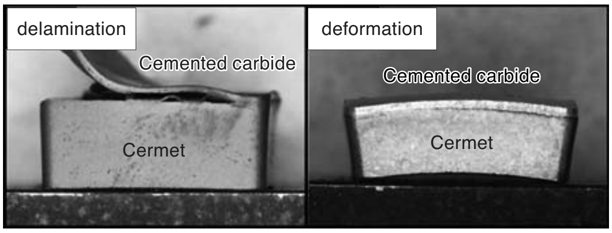

Photo 3. Appearance of delamination and deformation

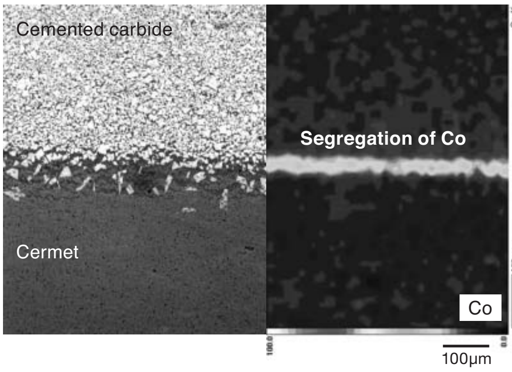

Photo 4. Migration of liquid phase

5. Solution Method

We thought that the differences in shrinkage properties between cemented carbide and cermet affected the delamination and deformation of the composite. Therefore, the cause of delamination and the mechanism of deformation were researched by evaluating and comparing the thermal shrinkage behavior of each material. **Figure 3** shows the thermal shrinkage behavior of the cemented carbides and cermets.

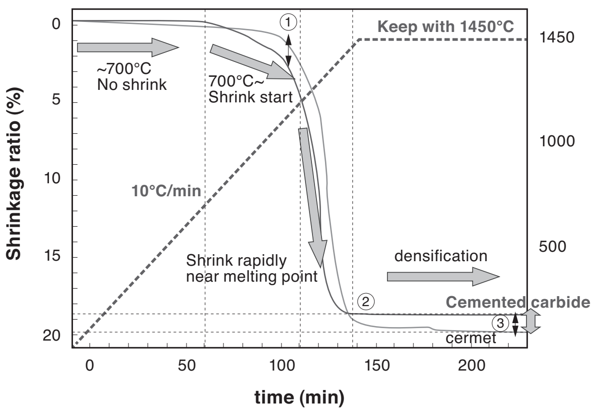

Fig. 3. Comparison of shrinkage behavior

There are three main differences in shrinkage behavior:

1: The shrinkage ratio of cermet in the range of 800-1100°C, a solid phase shrinkage area, is small;
2: Timing of complete shrinkage of cermet is slow; and
3: The shrinkage ratio of cermet is large.

In order to investigate the influence for delamination and deformation by these differences, we confirmed the intermediate shapes of the composites sintered at 800, 1000 and 1200°C. **Photo 5** shows the composite shapes at each temperature.

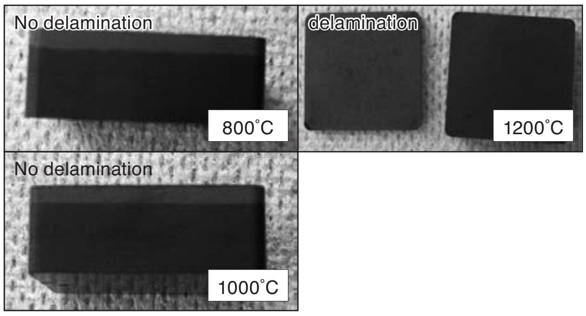

Photo 5. Appearance of sintering in low temperature

Although there was no delamination and deformation at 800 and 1000°C, there was delamination at the interfacial surface between cemented carbide and cermet at 1200°C. This fact shows that the delamination is caused greatly by the difference of shrinkage amount in the solid phase shrinkage area.

After conducting research on what affects the shrinkage difference in this solid phase shrinkage area, we found that the added volume of tungsten carbide is an influential factor. We further investigated in search of the favorable composite that restricts delamination by manufacturing cermets with different added amounts of tungsten carbide. As a result, for the composite using a cermet content of 10 vol%, tungsten carbide delaminated from the cemented carbide. For the composite using a cermet content of 15 vol%, tungsten carbide delaminated slightly. For the composite using a cermet content of 20 vol% or more, tungsten carbide did not delaminate. By optimizing the composition, the grain size, and the amount of auxiliary agent for molding, we succeeded in manufacturing a composite without delamination and deformation, as shown in **Photo 6**. We also succeeded in preventing migration of the liquid phase by controlling the melting point and wettability of bonded phases.

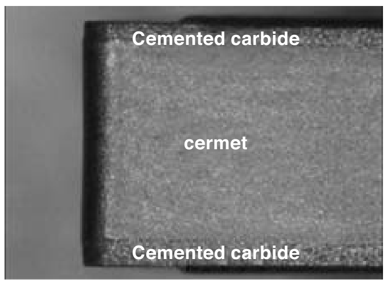

Photo 6. Appearance of good composite

6. Cutting Performance

To evaluate the cutting performance of the composites, a cutting tool with 20% reduction of tungsten was manufactured in accordance with the ISO classification of CNMG120408 shape, and was coated with 5 μm TiAlN film using the physical vapor deposition (PVD) method. We prepared three types of cutting tools, which were made of a cemented carbide monolayer, a cermet monolayer and a composite structure, and then we evaluated wear resistance by continuous cutting and fracture resistance by interrupted cutting. Wear resistance was evaluated using the following cutting conditions: cutting speed 220 m/min, feeding speed 0.3 mm/rev, depth 1.5 mm, work material SCM435 steel bar, and the wet-type turning method. **Figure 4** shows the result of the wear resistance test.

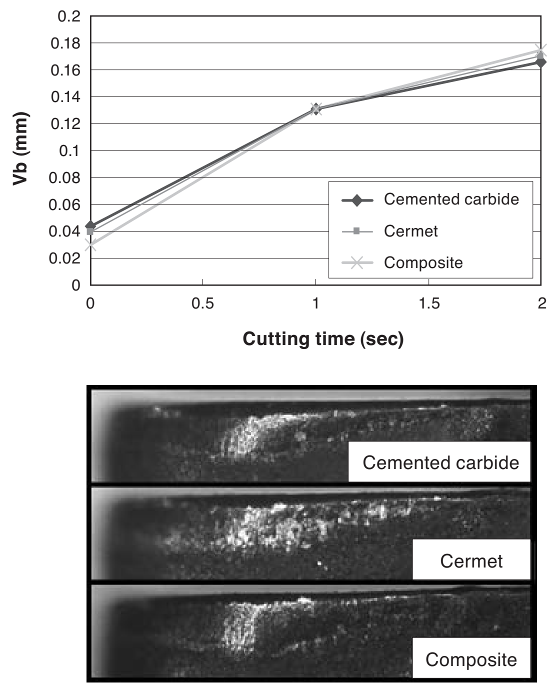

Fig. 4. Cutting performance of wear resistance

We confirmed that the amount of wear of the tungsten-reduced tools were about the same as in the cemented carbide monolayer and the cermet monolayer (with the same composition of metals as used for the intermediate layer of the composite tools). For the composite structure tools, the resistance to wear was about the same as in the conventional cemented carbides.

Defect resistance was evaluated using the following cutting conditions: cutting speed 60 m/min, feeding speed 0.5 mm/rev, depth 2 mm, work material SCM435 steel stock, and dry-type turning, for each of four corners. **Figure 5** shows the result of the defect resistance test.

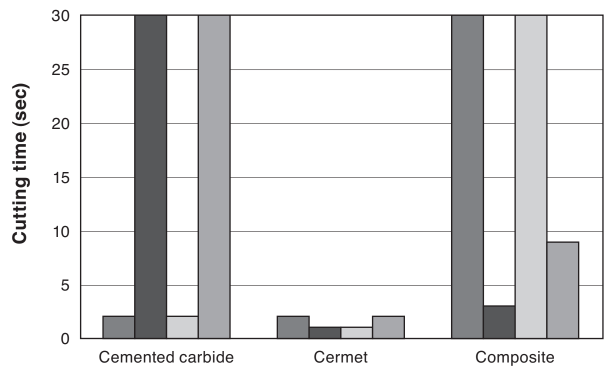

Fig. 5. Cutting performance of defect resistance

In the case of the cermet monolayer, all four corners fractured easily within three seconds, while in the cases of the cemented carbide monolayer and composite, two corners did not fracture, completing the cutting of 30 seconds. The composite test material showed defect resistance equivalent to that of cemented carbide.

7. Conclusion

We were able to confirm that a cutting tool of composite structure made of cemented carbide and cermet with reduced tungsten usage by 20% has the same level of resistance to wear and fracture resistance as the cemented carbides, thus we were also able to accomplish our intermediate target for reducing tungsten usage. We will further proceed toward the final target of a 30% reduction in tungsten usage by the end of FY 2011, when the government's project ends. Our goal includes confirming ease of mass production and cutting performance in the wide range of cutting conditions for the rest of the period.

8. Acknowledgements

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References

(1) JOGMEC Report of metal materials 91: "Rare metal series 2009 demand, supply and change in price of chrome and tungsten"
(2) Tomoyuki Ishida, Hideki Moriguchi, Akihiko Ikegaya: "Fabrication of composite structural material of cemented carbides and cermets," Proceedings of PM2010. Florence, Italy, 2010-10-10/10-14, European Powder Metallurgy Association
(3) Suzuki H et al.: "Cemented carbides and sintered hard materials," Tokyo, Maruzen, 1986
(4) P. Fan, Z. Z. Fang & H. Y. Sohn: Acta Mater. 2007, v55, p.3111

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