New Milling Grades—ACU2500 for general purposes, ACP2000/ACP3000 for steel milling, and ACK2000/ACK3000 for cast iron milling

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In the machining industry, long tool life and high machining efficiency are required for cost reduction and productivity improvement, and sudden troubles need to be reduced for factory automation. Furthermore, machining facilities have been increasingly integrated into single facilities that can process various work materials. In such circumstances, we have developed a general-purpose grade "ACU2500" that achieves a stable and long tool life in the milling of a wide range of work materials including steel and cast iron. We have also developed special grades "ACP2000 / ACP3000" and "ACK2000 / ACK3000" that offer high machining efficiency and long tool life in steel milling and cast iron milling, respectively. While covering a wide variety of work materials, these five grades demonstrate 1.5 times longer tool life and twice higher efficiency than conventional grades, enabling significant cost reduction and productivity improvement.

Keywords: indexable insert, milling, CVD, PVD

1. Introduction

Regarding indexable inserts used for machining, grades coated with a hard ceramics coating on the surface of the cemented carbide alloy substrate ("coated grades," see Fig. 1) have been increasingly used due to an outstanding balance between wear resistance and fracture resistance compared to other tool grades. At present, coated grades account for 70% of all indexable inserts.

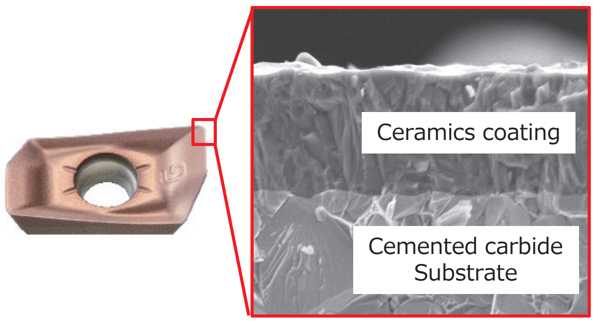


Fig. 1. Coated grade

In the machining site of the automotive and other industries, there are growing needs to reduce costs by improving the tool life, to increase productivity by achieving high-efficiency machining, and to automate equipment by reducing sudden problems. Recently, efforts have been made to consolidate machining equipment. There have been an increasing number of worksites where various work materials are machined using a single unit of machining equipment.

To meet such needs, Sumitomo Electric Industries, Ltd. developed ACU2500, a general-purpose grade that achieves a stable and long tool life in the milling (Photo 1) of various work materials including steel and cast iron. We also developed special grades ACP2000/ACP3000, which achieve high-efficiency machining and a stable and long tool life in the milling of steel, as well as ACK2000/ACK3000, which achieve high-efficiency machining and a stable and long tool life in the milling of cast iron. This paper reports the technical features and performance of these five grades.

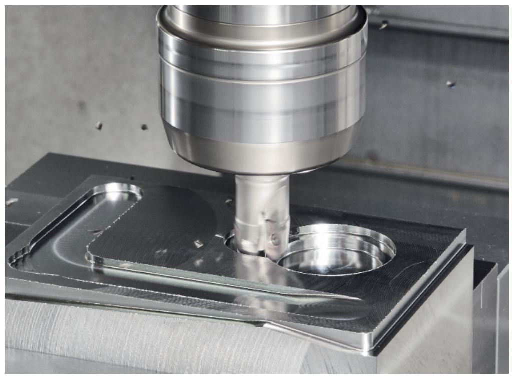


Photo 1. Example of milling

2. Technical Features of the New Grades

2-1 Positioning of the new grades

Figure 2 shows the positioning and recommended usage range of ACU2500 (a general-purpose grade), ACP2000/ACP3000 (grades for steel), and ACK2000/ACK3000 (grades for cast iron). For ACU2500, a newly developed PVD*[1] coating is applied to the cemented carbide alloy substrate, which is characterized by an outstanding balance between wear resistance and toughness. ACU2500 can be used for various work materials including steel and cast iron. For ACP2000 and ACK2000, which are special grades for steel and cast iron, a newly developed CVD*[2] coating is applied. They achieve a stable and long tool life under high-speed, high-efficiency machining conditions. For ACP3000 and ACK3000, a newly developed PVD coating is applied. They achieve a stable and long tool life in heavy intermittent machining.

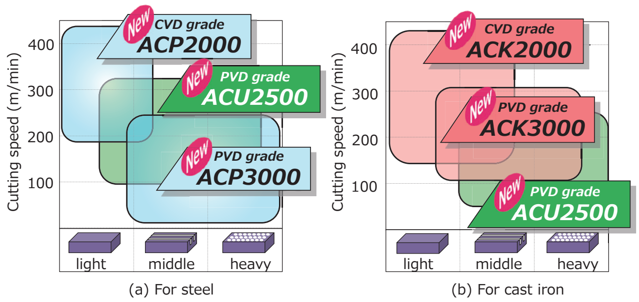


Fig. 2. Positioning of the new grades

2-2 Features of the new PVD coating

The newly developed PVD coating was applied to the three grades: ACU2500, ACP3000, and ACK3000. The new PVD coating has two main features. First, it improves wear resistance by the AlTiCrBN-based super-multilayer coating. Second, it improves stability by enhancing the interface adhesion strength between the coating and cemented carbide substrate.

To elucidate the mechanism of damage to the PVD coating in milling, we performed milling of steel using conventional PVD coating, and the cutting edge was closely observed. The results of observation of the cutting edge from the cross-section direction are shown in Fig. 3.

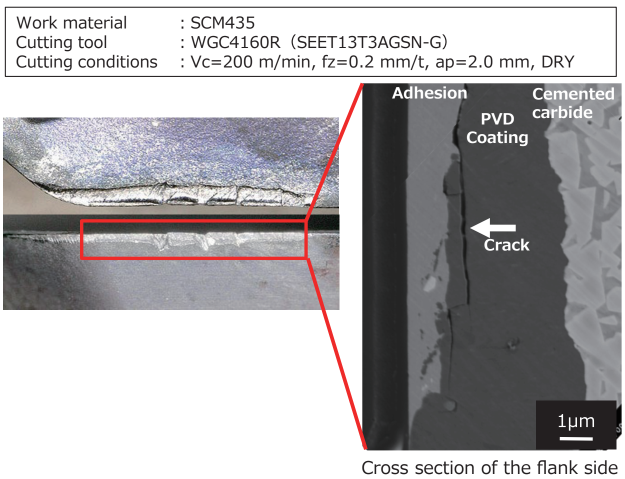


Fig. 3. Observation of damage to conventional PVD coating in steel machining

We found that cracks were generated in the coating in the worn area on the flank side and that damage progressed with the fracture of the coating. To improve the coating strength, we tried microstructure fining by adding a new element. We succeeded in attaining an ultra-fine microstructure of the coating of a few nanometers by adding boron (B) (Fig. 4).

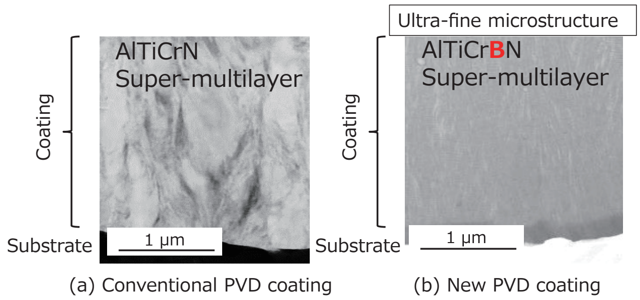


Fig. 4. Microstructure of the cross section of the conventional and new PVD coating

When cast iron was machined using the conventional PVD coating, sudden delamination occurred at the interface between the cemented carbide substrate and the coating, resulting in unstable tool life. We applied Sumitomo Electric's proprietary high-adhesion technology. In the scratch adhesion strength test*[3]. the new PVD coating attained an adhesion strength 1.5 times that of conventional PVD coating, as shown in Fig. 5.

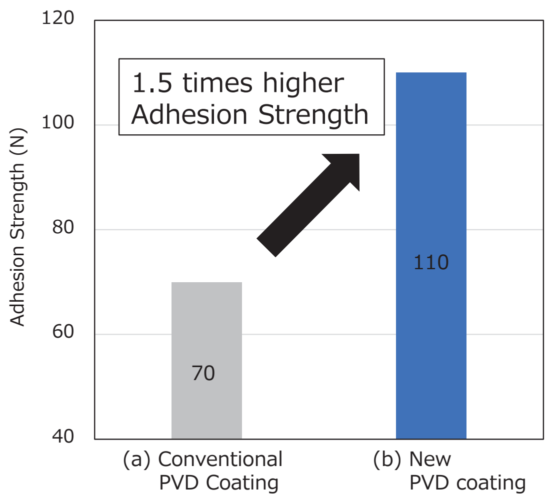


Fig. 5. Comparison of adhesion strength between conventional and the new PVD coating

Figure 6 shows the results of a cutting evaluation using the new PVD coating that has the features discussed above. The new PVD coating achieved a stable and long tool life of 1.5 times or more that of conventional PVD coating.

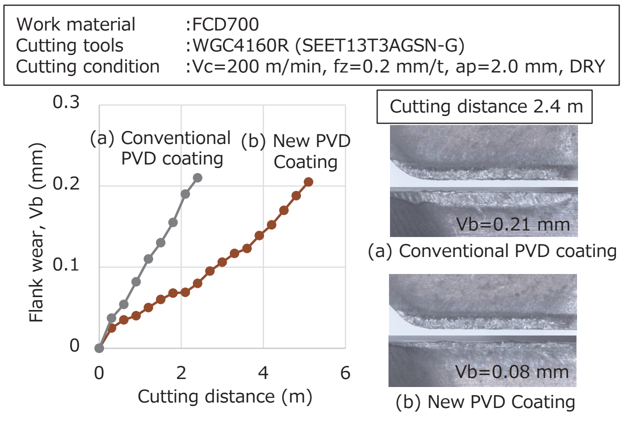


Fig. 6. Cutting performance of the new PVD coating

2-3 Features of the new CVD coating

The newly developed CVD coating was applied to two grades: ACP2000 and ACK2000. Comparison between conventional CVD coating and the new CVD coating is shown in Fig. 7. The new CVD coating has two main features. First, it has improved wear resistance by using alumina whose crystalline orientation is controlled and by increasing the coating thickness. Second, it has improved stability by introducing high compressive stress.

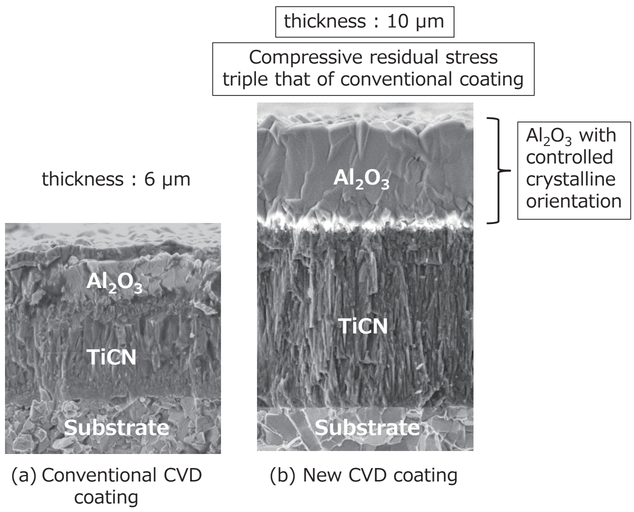


Fig. 7. Features of the new CVD coating

The CVD coating contains an alumina layer, which is characterized by outstanding thermal resistance, and therefore enables high-speed machining compared to PVD coating. Notably, during high-speed machining, wear on the rake surface side (which is scratched by chips) must be reduced. Thus, it was necessary to improve the strength of the alumina layer. For the new CVD coating, we developed an alumina coating comprised of alumina crystallites oriented in parallel with the crystal face perpendicular to the chip shearing direction (i.e., in the c-axis direction perpendicular to the cross section of the coating). Various studies were conducted on coating parameters to control crystalline orientation. For the new CVD coating, we formed an alumina coating with 90% or more of alumina crystallites oriented in the c-axis direction, as shown in Fig. 8.

In general, CVD coating is subject to residual tensile stress, which causes a problem of fracture due to impact during intermitted machining. Recently, a technology was developed to introduce compressive stress by performing surface treatment after coating and thereby improve fracture resistance. Sumitomo Electric developed a new technique and succeeded in introducing compressive stress triple or more that of conventional coating. For the new CVD coating, the coating thickness was increased from 6 μm (conventional coating) to 10 μm to further improve wear resistance. We improved wear resistance by introducing high compressive stress without undermining the fracture resistance.

Cutting evaluation was conducted using the new CVD coating that has the features discussed above. The results are shown in Fig. 9. It achieved stable and long tool life of 1.5 times or more compared to conventional CVD coating under high-speed cutting conditions.

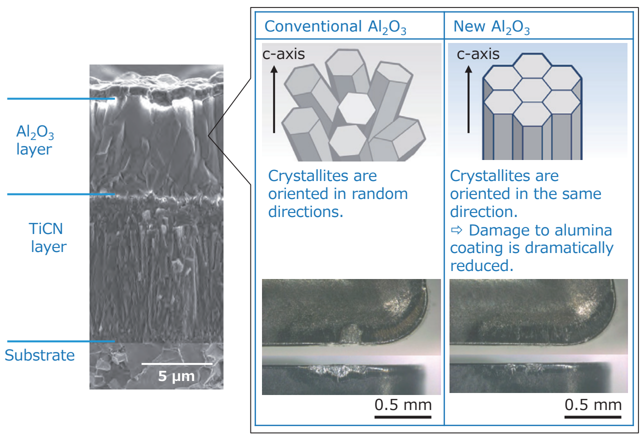


Fig. 8. Comparison of crystalline orientation of the alumina layers

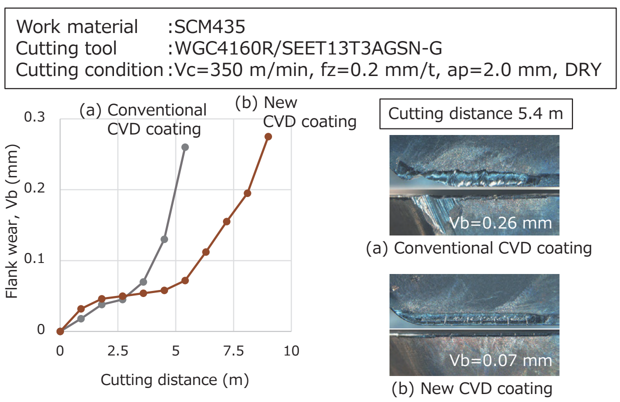


Fig. 9. Cutting performance of the new CVD coating

2-4 Features of the new cemented carbide substrate

In milling, tools repeat the cycles of contact with and separation from a workpiece. Thus, the cutting edge of a tool is subject to repeated cycles of expansion and shrinkage due to temperature change. This is likely to cause damage called thermal crack, which is one of the factors that reduces the tool life. To improve thermal crack resistance, we worked to increase the thermal conductivity of the cemented carbide substrate. The sintering condition was improved in addition to achieving uniform grain size of the WC raw material. As shown in Fig. 10, it achieved 1.5 times higher thermal conductivity than that of the conventional substrate. Figure 11 shows the results of a cutting test. The newly developed cemented carbide substrate demonstrated good thermal crack resistance.

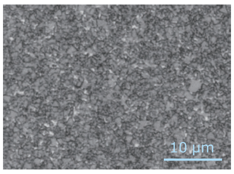
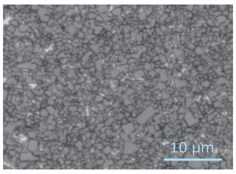
	Conventional substrate	New substrate
Thermal conductivity λ[W/m·K]	78	**115**
structure		

Fig. 10. Thermal conductivity and alloy microstructure of the new cemented carbide substrate

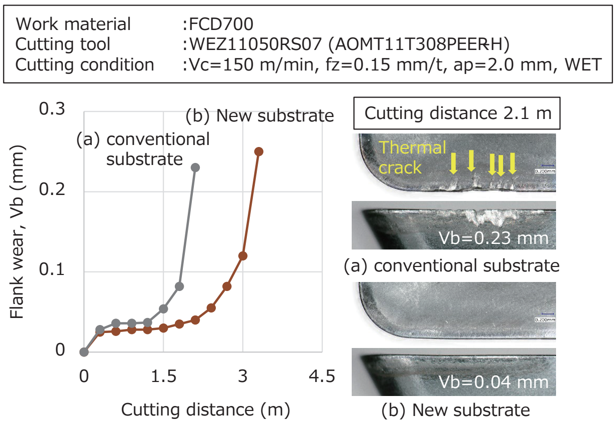


Fig. 11. Cutting performance of the new cemented carbide substrate

3. Examples of Machining

Examples of machining by users using ACU2500 (a general-purpose grade), ACP2000/ACP3000 (grades for steel), and ACK2000/3000 (grades for cast iron) are presented in Figs. 12 to 16. Figure 12 shows an example of machining by a user of ACU2500. The tool life of ACU2500 was 1.5 times or more of the conventional product and a competitor's product on various work materials such as steel, cast iron, and stainless steel. The results of machining of an automotive part (alloy steel) using ACP2000 are shown in Fig. 13. The tool life of ACP2000 was 1.8 times that of the conventional product due to good wear resistance and chipping resistance. Figure 14 presents the results of machining of a die part (die steel) using ACP3000. The tool life of ACP3000 was 1.7 times that of the conventional product due to excellent adhesion. The results of machining of a cylinder block (FC250) using ACK2000 are shown in Fig. 15. The tool life of ACK2000 was 2.3 times that of the conventional product due to outstanding wear resistance and chipping resistance. Figure 16 shows the results of machining of a machine part (FCD450) using ACK3000. The tool life of ACK3000 was 2.6 times that of the conventional product due to good wear resistance.

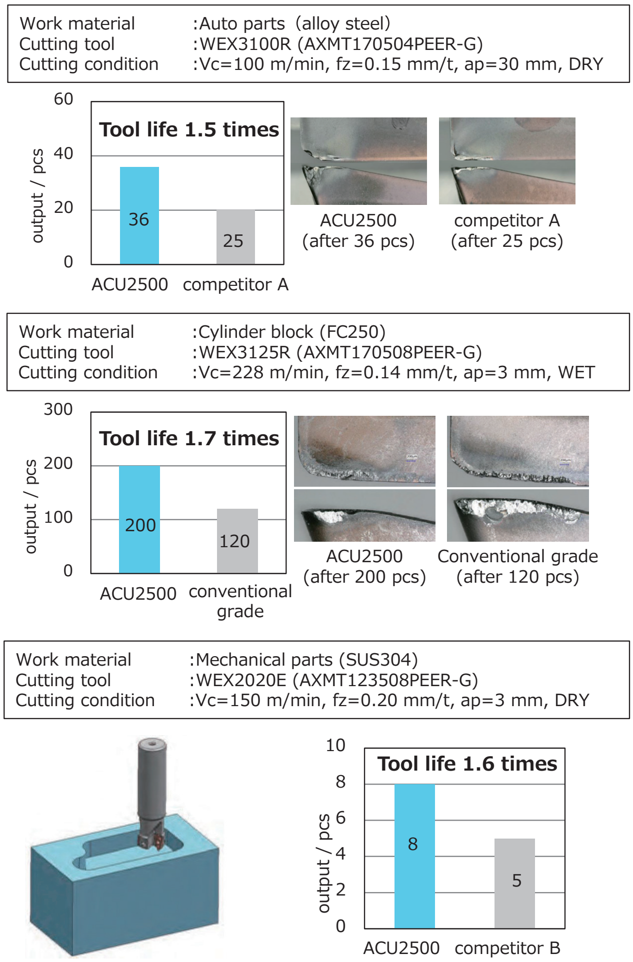


Fig. 12. Example of machining using ACU2500

Work material	:Auto parts (alloy steel)
Cutting tool	:WGX13125R (SEMT13T3AGSR-G)
Cutting condition	:Vc=335 m/min, fz=0.08 mm/t, ap= 2 mm, DRY

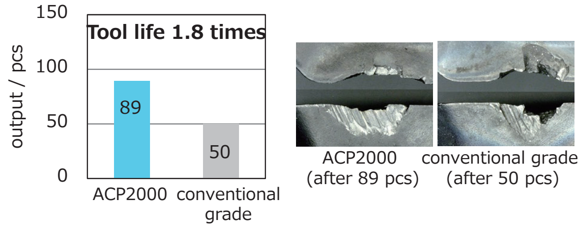


Fig. 13. Example of machining using ACP2000

Work material	:Mold parts (die steel)
Cutting tool	:WGC4160R (SEET13T3AGSN-G)
Cutting condition	:Vc=225 m/min, fz=0.13 mm/t, ap=3 mm, WET

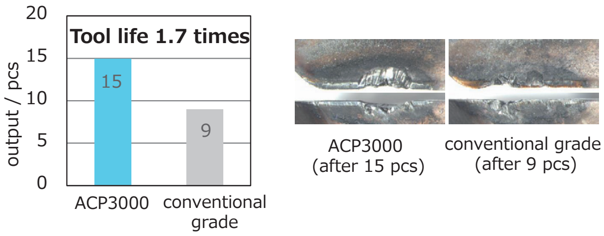


Fig. 14. Example of machining using ACP3000

Work material	:Cylinder block (FC250)
Cutting tool	:PWS4125R (LNMX160608PNSN-H)
Cutting condition	:Vc=300 m/min, fz=0.3 mm/t, ap=4 mm, WET

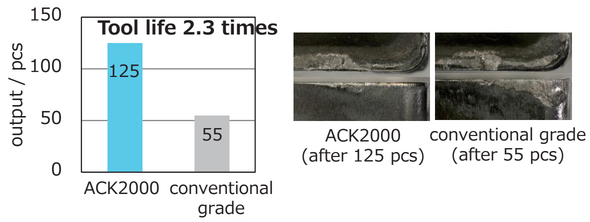


Fig. 15. Example of machining using ACK2000

Work material	:Mechanical parts (FCD450)
Cutting tool	:PWS4100R (LNMX160608PNSN-H)
Cutting condition	:Vc=200 m/min, fz=0.2 mm/t, ap=2 mm, DRY

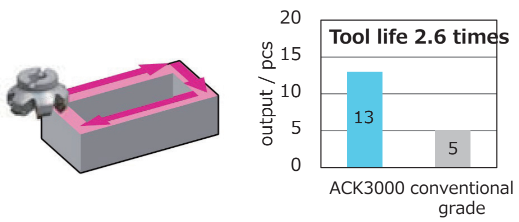


Fig. 16. Example of machining using ACK3000

4. Conclusion

As discussed above, the five types of new grades, to which the newly developed PVD coating, CVD coating, and cemented carbide substrate are applied, ensure a stable and long tool life. We believe that these grades will contribute significantly to reducing costs and improving productivity in machining operations.

Technical Terms

*1 PVD: PVD is the abbreviation for physical vapor deposition. A ceramic coating is allowed to deposit by ionizing a target and gas by arc discharge or other means for reaction.

*2 CVD: CVD is the abbreviation for chemical vapor deposition. A reactive gas is fed onto the surface of a base material, and a ceramic coating is allowed to deposit by chemical reaction.

*3 Scratch adhesion strength test: In this evaluation technique, a diamond indenter is placed in close contact with the surface of a coating, and it is moved while applying a load to measure the load when the coating is delaminated.

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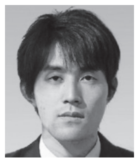

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