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Milling Grades 'ACS2500 and ACS3000' for Exotic Alloys

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Exotic alloys such as Ni-based alloys, cobalt (Co)-based alloys, and titanium (Ti) alloys are widely used for equipment and parts in aerospace and automotive industries due to their superior resistance against heat and corrosion. There has been growing demand for tools for machining these alloys. When cutting exotic alloys, the workpiece material is likely to adhere onto the cutting edge of a tool, resulting in a sudden fracture of the cutting edge of the tool. The tool life is significantly shorter than that of tools for cutting general steel. Thus, demand for cutting tools with stable performance and long tool life has been increasing. The newly developed ACS2500 and ACS3000 are designed to improve wear resistance and fracture resistance by applying a newly developed physical vapor deposition (PVD) coating and special cemented carbide substrate. These coated carbide grades help reduce cutting edge replacement frequency and tool consumption by extending tool life, thus contributing to the reduction of machining costs.

Keywords: difficult-to-cut material, cutting tool, PVD, stable performance and long tool life, high-efficiency machining

1. Introduction

Indexable inserts used for cutting tools, which are made by coating on the surface of a cemented carbide substrate with a hard ceramic film (hereinafter referred to as coating grade), have better-balanced wear resistance and fracture resistance compared to other inserts. Due to such distinctive features, use of these insert grades has been expanding year by year, and they currently account for 70% of all indexable insert grades.

Recently, nickel (Ni)-based alloys, cobalt (Co)-based alloys, titanium (Ti) alloys, and other materials, having excellent heat resistance and corrosion resistance, are often used for equipment and parts in the aerospace, oil and gas, medical, and automotive industries, and their use is expected to further expand in the future. These materials are characterized by good high-temperature strength, and tools are likely to have adhesion onto cutting edge during cutting, resulting in significant reduction in the tool life due to sudden fracture of the cutting edge of the tool and other factors. Therefore, there has been an increase demand for cutting tools with stable performance and long tool life in order to cut difficult-to-cut materials.

To meet such market needs, Sumitomo Electric Industries, Ltd. has developed and released two new grades, ACS2500 and ACS3000. ACS2500 is a new PVD*[1] coated grade that achieves long tool life and high-efficiency machining when milling difficult-to-cut materials, especially titanium alloys, and ACS3000 is a new coated grade that achieves stable performance and long tool life when machining heat-resistant alloys in a wide application range. This paper reports the development targets, features, and cutting performances of these two grades.

2. Technical Features of New Grades

2-1 Issues in milling difficult-to-cut materials

To identify issues in milling difficult-to-cut materials, we collected used tools from end users and analyzed the failure mode in depth. The analysis revealed that the damage called thermal cracks (Fig. 1) and chippings caused by the cracks are the major failure modes for machining titanium alloys. Since a milling tool, which rotates during machining, repeatedly makes contact with and separates from the workpiece material, the cutting edge of the tool repeatedly expands and contracts due to temperature changes. The thermal cycle causes distortion in a tool that is made from several materials with different properties, resulting in heat cracks. When titanium alloy with a low thermal conductivity is machined, in particular, the tool generates more heat and thermal cracks. On the other hand, when nickel-based alloys such as Inconel*[2] are machined, tools are subject to fracture mainly due to heavy wear. When wear progresses, the strength of the cutting edge decreases, leading to breakage.

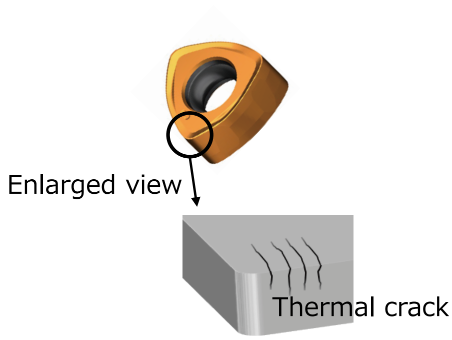


Fig. 1. Schematic diagram of thermal crack

2-2 Application ranges of ACS2500 and ACS3000

Figure 2 shows the application ranges of two grades: ACS2500 for titanium alloys and ACS3000 for Inconel alloys along with their recommended usage ranges. ACS2500 is a grade for titanium alloy milling, having a newly developed cemented carbide substrate and coating film with excellent thermal-crack resistance. ACS3000, applying a newly developed coating film, achieves long tool life with its excellent wear resistance for Inconel milling.

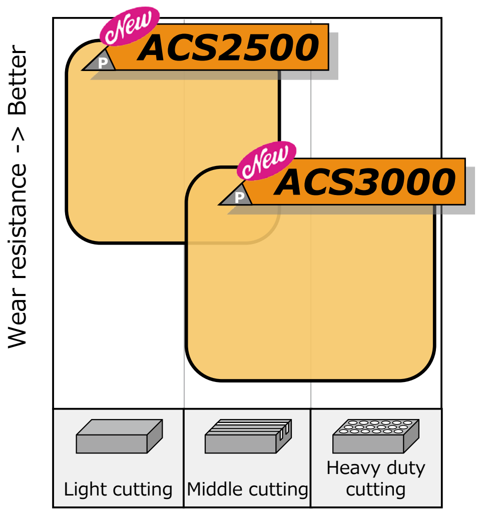


Fig. 2. Recommended application ranges of ACS2500 and ACS3000

2-3 Features of the new PVD film

The newly developed coating film is applied to both ACS2500 and ACS3000. The coating film mainly features (1) improved strength and wear resistance with the super-multilayered structure of ultra-fine grained AlTiBN and (2) improved stability with higher adhesion strength between the coating film and cemented carbide substrate. To understand the mechanism of damage of coating films during difficult-to-cut material milling, we machined Inconel 718 using a milling tool with a conventional coating film and closely observed the cutting edge. Photo 1 shows the results the cross sectional pictures of damaged cutting edge.

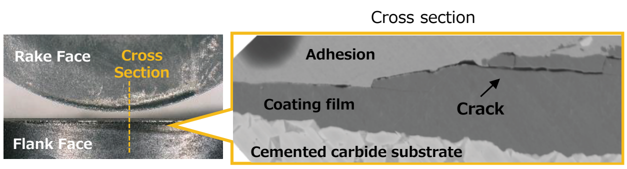


Photo 1. Cross sectional morphology on the damaged cutting edge

The picture reveals that the crack in the conventional coating film parallel to the interface between the film and substrate enlarged the damaged area. Suppressing these cracks is critical because damage will rapidly escalate when cracks are developed. We have made several trials to add new elements in order to obtain a finer coating structure and improve the coating strength. As a result, we have succeeded in developing the film structure as fine as several nm by adding boron (B) (Photo 2).

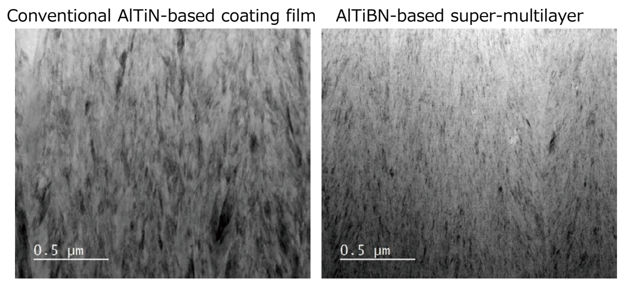


Photo 2. Cross sectional structure of new coating film

In addition, in the milling of difficult-to-cut material using a tool with a conventional coating film, tool life tends to be unstable due to delamination of the coating between the cemented carbide substrate and the film. To address this problem, we applied our original high adhesion technique to the interface. The new coating film has achieved an adhesion strength of 1.5 times that of conventional coating films in a scratch adhesion strength test*3 (Fig. 3).

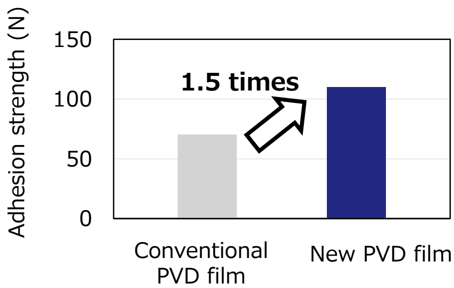


Fig. 3. Adhesion strength of the new coating film

2-4 Features of the new cemented carbide substrate

To improve thermal-crack resistance, efforts were made to increase the strength of the cemented carbide

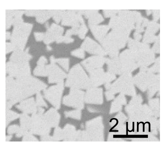
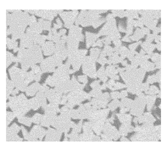
	Conventional carbide substrate	Newly developed carbide substrate
Transverse rupture strength (GPa)	3.8	4.4
Microstructure		

Fig. 4. Characteristics of cemented carbide substrates

substrate. We have successfully developed a new cemented carbide substrate that achieves a transverse rupture strength 1.2 times that of conventional substrates by uniform WC raw materials and improved sintering conditions (Fig. 4).

2-5 Cutting performances of ACS2500 and ACS3000

We have rolled out ACS2500, which is the combination of the ultra-fine grained AlTiBN film and the S20-grade cemented carbide substrate, and ACS3000, which is the combination of the film and the S30-grade substrate.

The cutting test of titanium alloys was conducted using ACS2500. The results are shown in Fig. 5. The higher transverse rupture strength of the cemented carbide substrate has reduced chippings caused by thermal cracks and the tool life of ACS2500 is 1.9 times that of conventional grade.

The cutting test of Inconel 718 was conducted using ACS3000. The results are shown in Fig. 6. ACS3000 demonstrated a longer tool life 1.6 times that of conventional grades.

3. Examples of Machining with ACS2500 and ACS3000

Figures 7 and 8 show examples of machining by end users using ACS2500 for titanium alloy milling and ACS3000 for heat-resistant alloy milling. The results of the machining of an airplane part (titanium alloy) using ACS2500 are shown in Fig. 7. The tool life of ACS2500 was double that of a competitor's product with the excellent thermal-crack resistance.

The results of the machining of a machine part (Hastelloy*4) using ACS3000 are shown in Fig. 8. The tool life of ACS3000 was five times that of a competitor's product with the excellent wear resistance.

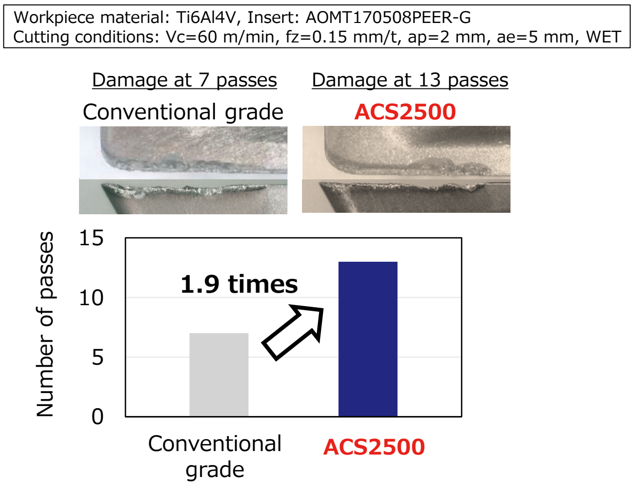


Fig. 5. Evaluation results of titanium alloy cutting with ACS2500

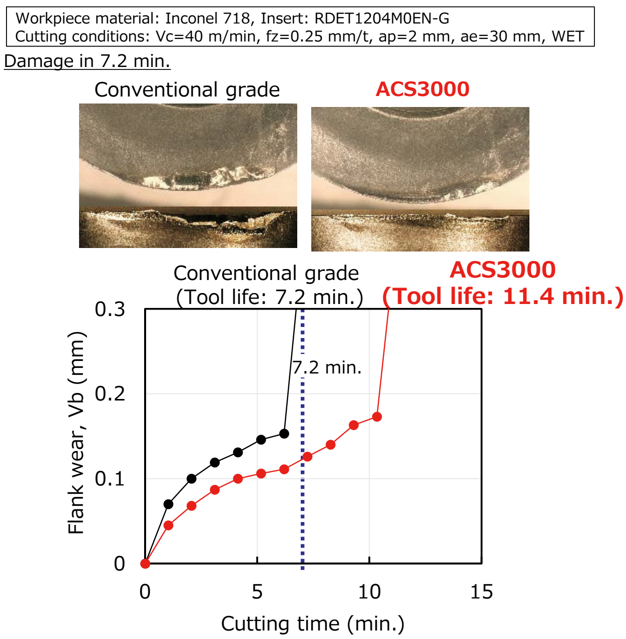


Fig. 6. Evaluation results of Inconel 718 cutting with ACS3000

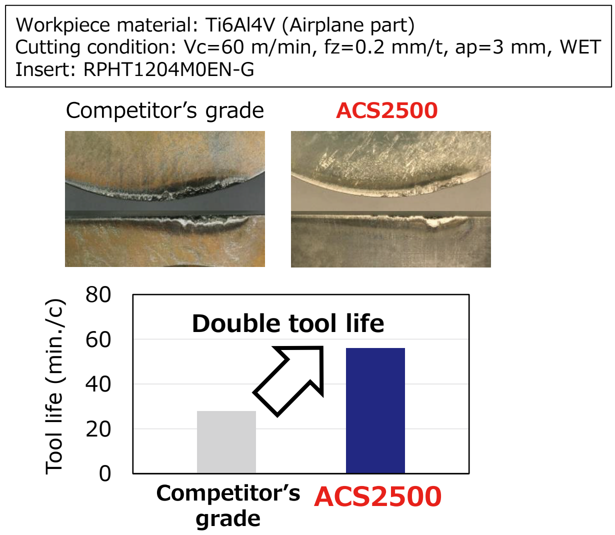


Fig. 7. Application example of ACS2500

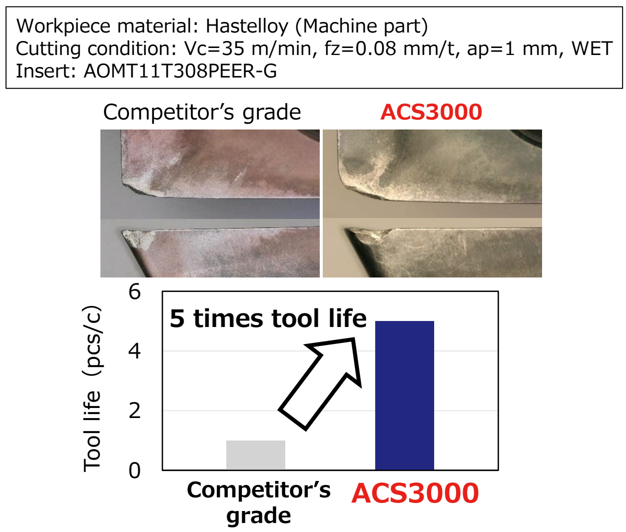


Fig. 8. Application example of ACS3000

4. Conclusion

As described above, we have developed a new PVD coating film with superior wear resistance and a new cemented carbide substrate with outstanding thermal-crack resistance, and applied them to ACS2500 and ACS3000, which have achieved stable performance and double the tool life than that of conventional grades. These two grades will make a significant contribution to cost reduction and productivity improvement in milling difficult-to-cut materials.

Technical Terms

∗1 Physical vapor deposition (PVD): A method for depositing a ceramic film on the substrate surface, by reacting target materials ionized by arc discharge or other means with gas.

∗2 Inconel: A type of Ni-based heat-resistant alloy. It is a trademark or registered trademark of Huntington Alloys Corporation.

∗3 Scratch adhesion strength test: A test method for measuring a load at which delamination occurs when a diamond indenter is pressed onto a coating film surface and moved across the surface with elevated load.

∗4 Hastelloy: A type of Ni-based heat-resistant alloy. It is a trademark or registered trademark of Haynes International, Inc.

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