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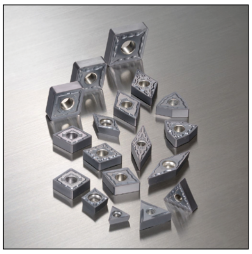

Turning Grade AC5005S for Exotic Alloys

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Exotic alloys, such as nickel alloys, cobalt alloys, and titanium alloys, are widely used for equipment and parts in the aircraft and automotive industries due to their superior heat and corrosion resistance. There has been a growing demand for the machining tools for these alloys. We released the AC5015S and AC5025S for exotic alloy turning, which use the new physical vapor deposition (PVD) coating technology. Meanwhile, there is a strong need for cutting tools that enable high-efficiency machining. To satisfy these demands, we have developed a new exotic alloy turning carbide grade, AC5005S, which shows excellent wear resistance, plastic deformation resistance, and fracture resistance in high efficient machining. Together with the existing AC5000S series, the new AC5005S will reduce machining costs in a wide range of exotic alloys turning operation.

Keywords: difficult-to-machine material, cutting tool, PVD, high-efficiency machining

1. Introduction

Indexable inserts used for cutting tools, which are made by coating the surface of a cemented carbide*[1] base material (hereafter referred to as "coating grade") with a hard ceramic film, have better-balanced wear resistance and fracture resistance compared to other inserts. Due to such distinctive features, use of these inserts has been expanding year by year, and they currently account for more than 70% of all indexable inserts.

In recent years, so-called "difficult-to-machine materials," such as nickel (Ni)-based alloys, cobalt (Co)-based alloys, and titanium (Ti) alloys, having excellent heat resistance and corrosion resistance, have widely been used in the aircraft, oil and gas, medical, and automotive industries, and their use is expected to further expand in the future. Difficult-to-machine materials have excellent mechanical and thermal properties. On the other hand, the problems associated with their machining are that they increase the cutting-edge temperature of the tool and that they melt and adhere to the tool, which can suddenly damage the tool and significantly reduce its tool life.

In response to customer need for machining difficult-to-machine materials, Sumitomo Electric Industries, Ltd. developed and released the AC5000S series, a new PVD*[2] coating grade that achieves outstanding stability and long tool life of the tool in a wide range of machining areas, and has been expanding its product lineup on a step-by-step basis.[(1)] Recently, we have developed and released a new coating grade, AC5005S, to meet customer need for higher efficiency machining and longer tool life than those of the existing AC5000S series. This paper reports the development process and performance of AC5005S.

2. Development Target for AC5005S

The AC5000S series responds to a wide range of machining conditions, from continuous to interrupted cutting. AC5015S meets the machining conditions from continuous to partially interrupted cutting, while AC5025S meets the need for machining operations ranging from partially to strongly interrupted cutting. Meanwhile, there was a growing need for a new grade capable of machining at a higher efficiency than AC5015S in order to further improve difficult-to-machine material machining efficiency.

For the purpose of clarifying the problems associated with high-efficiency machining with AC5015S, we analyzed the results of evaluation conducted by users. The analysis results revealed that (1) in a high cutting speed range exceeding 80 m/min, the cutting tool reaches the end of tool life due to the continuance of flank and crate wear (Fig. 1 (a)) and (2) in a high feed rate range exceeding 0.20 m/rev, the cutting tool reaches the end of tool life due to plastic deformation or notch wear of the cutting edge (Fig. 1 (b)). Based on the above findings, we started the development of AC5005S with the goal of extending its tool life to 1.5 times that of AC5015S under high-efficiency machining conditions (1) and (2) by making AC5005 wear resistance, plastic deformation resistance, and fracture resistance.

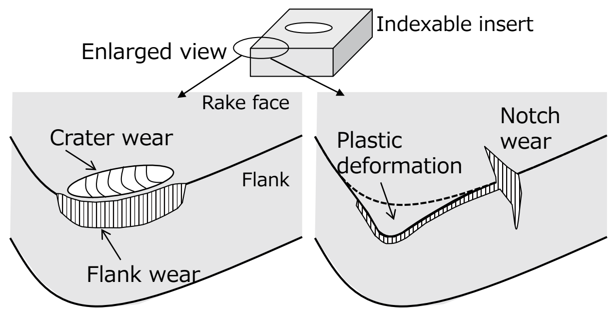

Fig. 1. Cutting edge fracture patterns

3. Features and Cutting Performance of AC5005S

3-1 Improvement in flank wear resistance, plastic deformation resistance, and fracture resistance

In high-efficiency machining of difficult-to-machine materials, the cutting edge of the tool is heated to a high temperature and its hardness decreases. As a result, the tool causes flank wear and plastic deformation. To avoid such trouble, cutting tools are required to maintain excellent mechanical properties even at high temperatures.

Cemented carbide is mainly composed of tungsten carbide (WC), which is a hard substance, and cobalt (Co), which is used as a binder phase. Since Co becomes soft when heated to a high temperature, the high-temperature hardness of cemented carbide depends mainly on the amount of the binder phase. The high-temperature hardness increases as the amount of the binder phase decreases. On the other hand, the fracture toughness decreases due to a deficiency of the bond, making cemented carbide easy to fracture.

In order to solve the above problem, we worked on the development of a new binder phase that can work as a substitute for Co. As a result, we developed a new binder phase having excellent heat resistance and succeeded in improving the high-temperature properties of cemented carbide. The structure of the new cemented carbide is shown in Fig. 2. For the purpose of evaluating the high-temperature properties of the new cemented carbide, we carried out a high-temperature compression test (1,000°C, 5 kN) of conventional cemented carbide containing Co as the binder phase and the new cemented carbide containing the newly developed binder phase. The test results showed that the cemented carbide containing the newly developed binder phase reduced the deformation by 50% compared to that of cemented carbide containing Co as the binder phase, verifying that the new cemented carbide improved its plastic deformation resistance (Fig. 3).

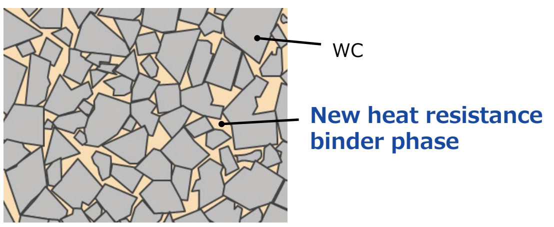

Fig. 2. Structure of new cemented carbide

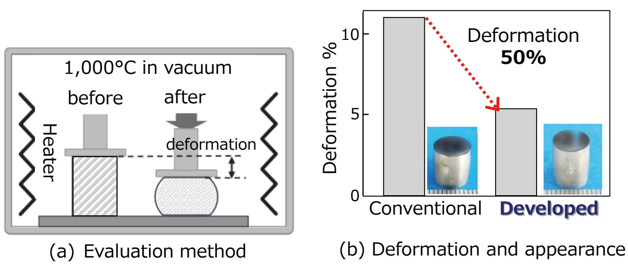

Fig. 3. High-temperature compression test

On the other hand, it was found that the newly developed binder phase was inferior to Co in wettability with WC, and this led to the formation of fine voids in the cemented carbide structure and reduced the fracture toughness of the new cemented carbide. To minimize the formation of fine voids and thus to improve the fracture toughness, we developed a new sintering technique. Using this technique, we developed new cemented carbide that breaks through the trade-off relation between high temperature hardness and fracture toughness that is specific to conventional cemented carbide containing Co as the binder phase (Fig. 4).

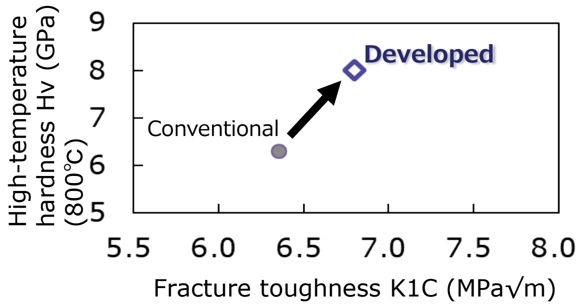

Fig. 4. Physical properties comparison

3-2 Improvement in crater wear resistance

A newly developed PVD coating film was used to improve the crater wear resistance of the new cemented carbide. Details of the process are described below. The new PVD coating film is used for three grades of the AC5000S series.

In order to clarify the mechanism of crater wear, Inconel*3 718, a Ni-based heat-resistant alloy, was turned with a conventional coating grade tool, and the cutting edge of the tool was observed in detail. In particular, the cutting edge of the tool at the initial stage of the turning, or three minutes after the start of the turning, was observed from the cross-sectional direction by cutting the cutting edge at cross section A-A' as shown in Fig. 5 (a). As a result, the coating film on the rake face was worn away, and melting and adhesion of the workpiece to the tool were found on the worn part (Fig. 5 (b)). For further detailed analysis, compositional analysis was conducted along B-B' using EDX*4. According to the analysis results, oxygen (O) and chromium (Cr) concentrations were high in some areas near the surface of the coating film (Fig. 5 (c)). The high O-concentration was estimated to be attributable to the generation of heat during the turning and resulting oxidation of the coating film. In order to suppress oxidation wear of the coating film, improving its oxidation resistance was indispensable. On the other hand, the high concentration of Cr was considered to have resulted from the diffusion of Cr contained in the workpiece into the coating film. The coating film used for the conventional grade was composed of AlTiCrN, and both the workpiece and coating film contained Cr. This was considered to have increased the affinity between the coating film and workpiece, making it easy for the latter to adhere to the former. At the same time,

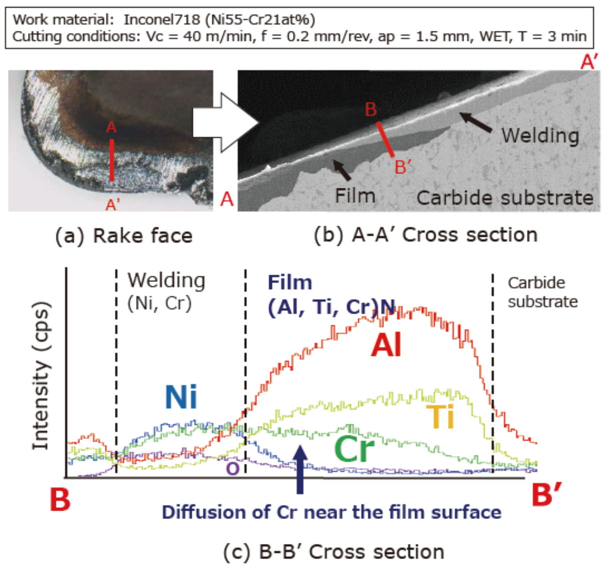

Fig. 5. Observation of damage at the crater wear from the cross section direction

the diffusion of Cr contained in the workpiece into the coating film was considered to have promoted diffusional wear.

Therefore, with an aim to improve the oxidation wear resistance and diffusion wear resistance of the coating film, we newly developed a Cr-free AlTiSiN film. The results of an oxidation test are shown in Fig. 6. Samples of conventional AlTiCrN films and newly developed AlTiSiN film both deposited on cemented carbide base materials were held in the air at 900°C for 30 minutes and were observed from the cross-sectional direction. The thickness of the oxidized layer of the conventional AlTiCrN film was 1.0 µm, while that of the newly developed AlTiSiN film was 0.4 µm, verifying that the oxidation resistance of the

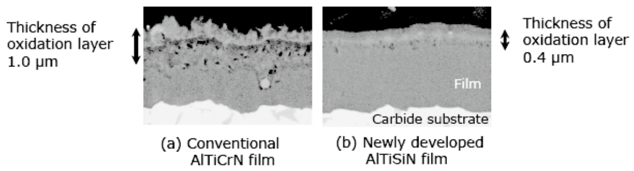

Fig. 6. Results of observation of the cross section after oxidation test

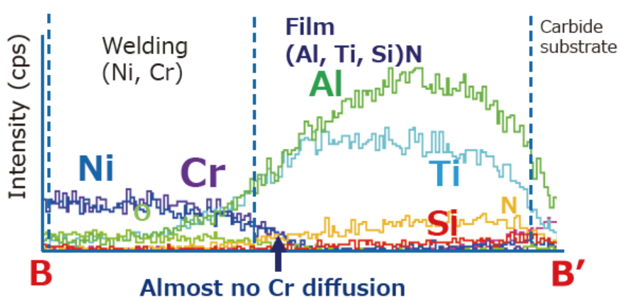

Fig. 7. Results of composition analysis of the crater wear on the AlTiSiN film

AlTiSiN film is two times or more higher than that of the AlTiCrN film. Figure 7 shows the results of the composition analysis of the crater wear portion from the cross-sectional direction at the time of three minutes after the start of turning Inconel 718 with a cutting tool coated with the newly developed AlTiSiN film. No diffusion of Cr was detected near the surface of the newly developed AlTiSiN film.

By combining this coating technology with cemented carbide containing the newly developed binder phase, we commercialized a new grade named AC5005S.

3-3 Cutting performance of AC5005S

Figure 8 shows the evaluation results for the wear resistance of AC5005S when used for turning Inconel 718 under high-speed conditions. As shown in this figure, AC5015S was rapidly worn away and reached the end of its tool life in a short period of time, while AC5005S demonstrated high wear resistance and achieved two times longer tool life.

Figure 9 shows the evaluation results for the wear/fracture resistance under high feed rate conditions. The wear/fracture resistance of AC5005S was 1.5 times higher than that of AC5015S.

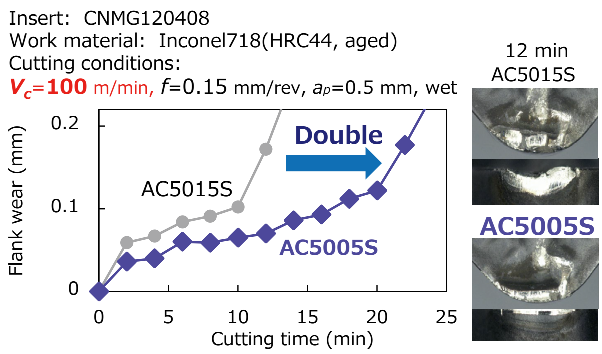

Fig. 8. Results of cutting test under high-speed conditions

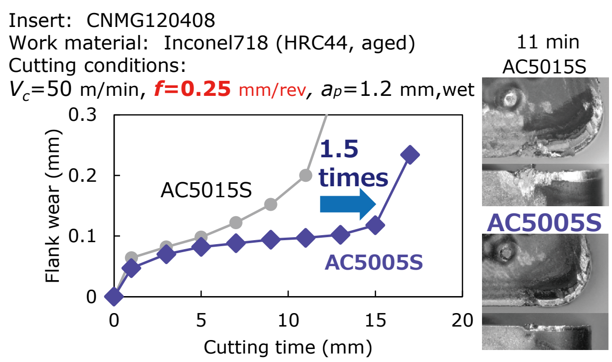

Fig. 9. Results of cutting test under high feed rate conditions

4. Examples of Machining with AC5005S

Figures 10 through 13 show examples of difficult-to-machine material machining by users using AC5005S.

Figure 10 shows the results of machining aircraft parts (Inconel 718), where the wear depth (Vb) of AC5005S on its flank was small even after machining the parts two times as many as those machined by a competitor's product.

Figure 11 shows the results of machining aircraft parts (Ti alloy). Under a cutting condition where the speed was 1.2 times higher than that of a conventional grade, AC5005S extended tool life to 1.6 times that of the conventional grade.

Figure 12 shows the results of machining industrial machine parts (15-5PH precipitation hardened stainless steel). Compared to a competitor's product, AC5005S increased tool life by a factor of 1.5 under the cutting conditions of 1.6 times the cutting speed, 1.4 times the feed rate, and 1.3 times the depth of cut.

Figure 13 shows the results of machining an industrial material (HRC50-55 high hardness steel). AC5005S suffered only slight damage even when used for cutting at a speed 1.2 times higher than that of a competitor's product.

5. Conclusion

As described above, the combination of cemented carbide with the newly developed binder phase and the new AlTiSiN-based PVD coating film has enabled AC5005S to ensure stable and long tool life in high-efficiency difficult-to-machine material turning operations. Together with AC5015S and AC5025S, the three grades of the AS5000S series will make a significant contribution to cost reduction and productivity improvement in turning difficult-to-machine materials.

Technical Terms

*1 Cemented carbide: A composite material of ceramics and a metal, consisting mainly of tungsten carbide (WC) and cobalt (Co).

*2 Physical vapor deposition (PVD): A method of coating the surface of a base substance with a ceramic film by reacting a metal with a gas in plasma.

*3 Inconel: A trademark or registered trademark of Huntington Alloys Corporation for a Ni-base heat-resistant alloy.

*4 EDX (Energy dispersive X-ray spectrometry): A method of detecting the elements composing an object and their concentration from the characteristic X-rays that are generated when the object is irradiated with electrons or X-rays.

Work material: inconel718 (Aircraft part)
Insert: CNMG190616N-EG
Cutting conditions:
v_c=50 m/min, f=0.3 mm/rev, a_p=3.5 mm, wet (7MPa)

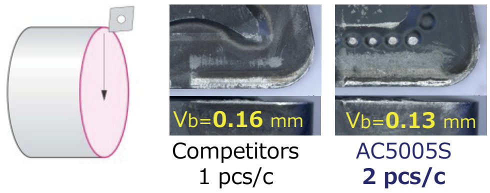

Fig. 10. Example of machining with AC5005S (1)

Work material: Ti-6Al-4V (Aircraft part)
Insert: CNMG120408N-EG
Cutting conditions:
Conventional: v_c=**60** m/min, f=0.25 mm/rev, a_p=3.0 mm, wet
AC5005S: v_c=**70** m/min, f=0.25 mm/rev, a_p=3.0 mm, wet

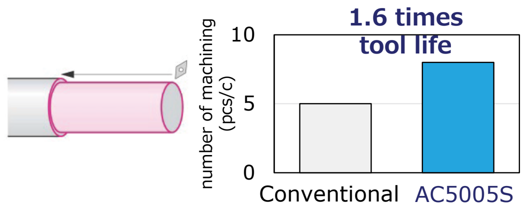

Fig. 11. Example of machining with AC5005S (2)

Work material: 15-5 PH Stainless Steel (machine part)
Insert: CNMG120412N-MU
Cutting conditions:
Competitors v_c=**30** m/min, f=**0.25** mm/rev, a_p=**2.0** mm, wet
AC5005S v_c=**50** m/min, f=**0.35** mm/rev, a_p=**2.5** mm, wet

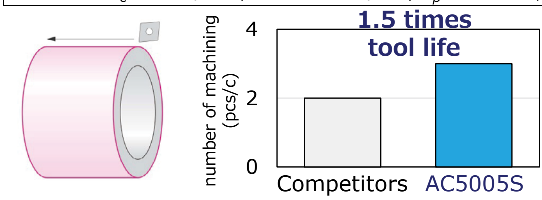

Fig. 12. Example of machining with AC5005S (3)

Work material: Steel (HRC50-55)(machine parts)
Insert: SNMG120412N-GU
Cutting conditions:
Competitors v_c=**50** m/min, f=0.4 mm/rev, a_p=1.5 mm, wet
AC5005S v_c=**60** m/min, f=0.4 mm/rev, a_p=1.5 mm, wet

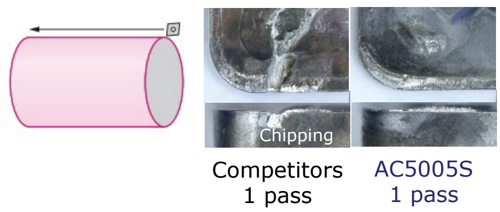

Fig. 13. Example of machining with AC5005S (4)

Reference

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