Turning Grades 'AC5000S' for Exotic Alloys

Shinya IMAMURA*, Keizo TANAKA, Shuhei MISUMI, Kazuhiro HIROSE, and Haruyo FUKUI

Exotic alloys, such as nickel alloys, cobalt alloys, and titanium alloys, are widely used for equipment and parts in the aircraft and auto industries due to their superior heat and corrosion resistance. There has been a growing demand for the machining tools for these alloys. When machined, exotic alloy work materials are likely to adhere to the edges of cutting tools, resulting in a sudden fracture of the tools. These tools have a significantly shorter life than those used for general steel. Thus, demand is high for cutting tools with stable performance and long tool life. The newly developed grades, AC5015S and AC5025S, are characterized by improved wear and fracture resistance with a state-of-the-art physical vapor deposition coating and special cemented carbide. These materials help reduce tool replacement frequency and tool consumption by extending tool life, thus contributing to the reduction of machining costs.

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

1. Introduction

Regarding indexable inserts for cutting tools, the usage ratio of coated materials (cemented carbide alloy base metals coated with a hard ceramic film) has been increasing year by year.

Compared to other tool materials, coated materials are characterized by an outstanding balance between wear resistance and fracture resistance. At present, coated materials account for 70% of all indexable insert materials.

Recently, nickel (Ni)-based metals, cobalt (Co)-based metals, titanium (Ti) alloys, and other materials are often used for equipment and parts in the aircraft, oil and gas, medical, and auto industries because they are characterized by superb heat resistance and corrosion resistance. The consumption of these materials is expected to increase significantly.

These materials are characterized by high temperature strength. When cutting these materials, they are likely to be welded onto the cutting edge of a tool, resulting in significant reduction in the tool life due to sudden fracture of the cutting edge of the tool, among other factors.

Against this backdrop, demand for cutting tools with stable performance and long tool life has been increasing in order to cut difficult-to-machine materials.

To meet such market needs, we have developed and marketed two products. One is AC5015S, a new physical vapor deposition (PVD)*[1]-coated material that achieves long tool life and high efficiency machining when turning difficult-to-machine materials, and the other is AC5025S, a new coated material that achieves stable performance and long tool life in interrupted machining.

This paper reports the development history and performance of these materials.

2. Development Target for AC5015S and AC5025S

To identify issues in turning difficult-to-machine materials, we collected used tools from the market and conducted in-depth analysis of the damage morphology.

The results are shown in Fig. 1. There were mainly two types of damage to the cutting edge.

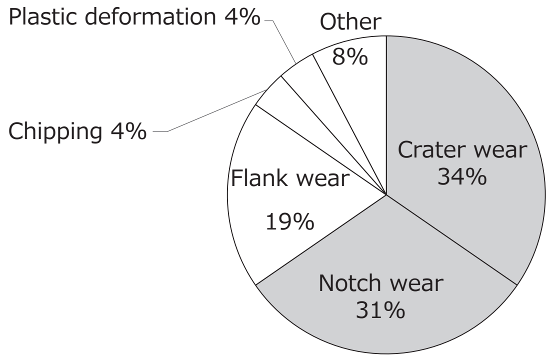

Fig. 1. Analysis of used tools

One was crater wear resulting from the abrasion of inserts generated by chips, and the other was boundary fracture that occurs near the area where the work material comes into contact with the tool initially (Fig. 2). We found that these types of damage account for 65% of total damage.

Thus, the target performance for AC5015S and AC5025S was to double the crater wear resistance and notch wear resistance compared to our conventional materials.

Meanwhile, we also found that there was strong market demand for high efficiency machining. Thus, we set a target for AC5015S to achieve a tool life equivalent to that of our conventional material under twice as high efficiency machining conditions as with the conventional material.

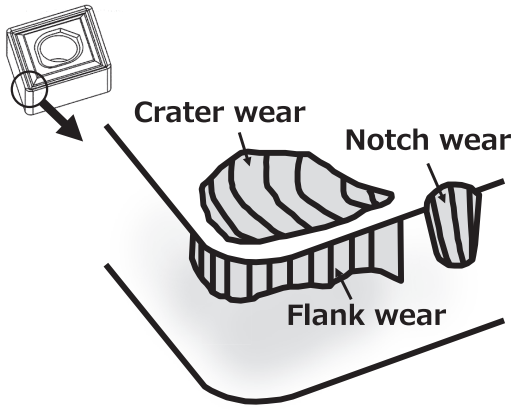

Fig. 2. Damage morphology on the cutting edge

3. Features of AC5015S and AC5025S

3-1 Efforts to improve crater wear resistance

To elucidate the mechanism of crater wear, we turned Inconel*2 718, an Ni-based heat-resistant alloy (our conventional coated material) and closely observed the cutting edge.

Notably, we cut the cutting edge in the initial stage (three minutes after the start of machining) on the A-A' cross section, as shown in Fig. 3, and observed it from the cross section direction.

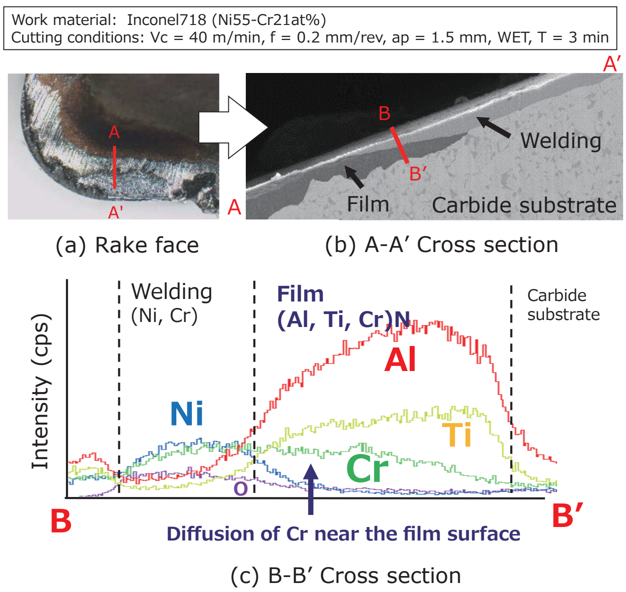

Fig. 3. Observation of damage at the crater wear from the cross section direction

We identified wear of the coating film on the face and welding of the work material on the worn area. To conduct in-depth analysis, we used energy dispersive X-ray spectrometry (EDX)*3 along B-B' to analyze the composition. We found that the concentration of oxygen (O) and chrome (Cr) was high in some areas near the surface of the coating film.

The high oxygen concentration is attributable to oxidization of the coating film due to heat generation during cutting. It is necessary to improve the oxidization resistance of the coating film to reduce oxidization wear.

The high Cr concentration is attributable to diffusion of Cr contained in the work material into the coating film. The composition of the coating film that was applied to the conventional material was AlTiCrN. Thus, both the work material and the coating film contained Cr. This is considered to have increased the affinity of these materials and increased the likelihood of welding of the work material on the coating film. This is also considered to have promoted diffusion wear due to diffusion of Cr in the work material into the coating film.

To improve oxidization wear resistance and diffusion wear resistance, we developed a new Cr-free AlTiSiN film. Figure 4 shows the results of an oxidation test.

We created samples of cemented carbide alloy base materials on which a conventional AlTiCrN film and the newly developed AlTiSiN film were formed. The samples were retained at 900°C in the atmosphere for 30 minutes, and were observed from the cross section direction.

The oxidation layer thickness of the conventional AlTiCrN film was 1.0 µm. Meanwhile, the oxidation layer thickness of the newly developed AlTiSiN film was 0.4 µm. The oxidization resistance properties of the AlTiSiN film were good, more than double that of conventional AlTiCrN film.

We also turned Inconel 718 using a cutting edge coated with the AlTiSiN film, and analyzed the composition of the crater wear area from the cross section direction three minutes after the start of machining.

The results are shown in Fig. 5. No diffusion of Cr was confirmed near the surface of the AlTiSiN film.

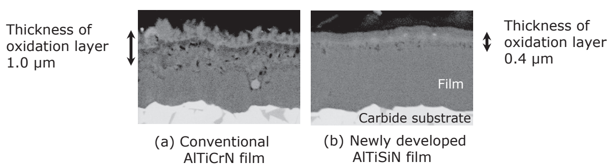

Fig. 4. Results of observation of the cross section after oxidation test

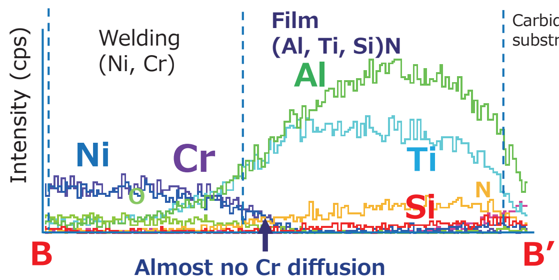

Fig. 5. Results of composition analysis of the crater wear on the AlTiSiN film

3-2 Efforts to improve notch wear resistance

During cutting, there is a large difference in stress applied between the areas where the work material comes into contact (on the ridge line of the cutting edge) and those where the work material does not. Fracture and wear are likely to occur near the boundary.

Fracture is likely to occur at the boundary when machining difficult-to-machine materials whose high temperature strength is high in particular. The tools must be tough.

Against this backdrop, we worked to increase the strength of the cemented carbide base metal to improve the notch wear resistance.

We developed a new cemented carbide alloy by increasing the strength of the WC raw materials, uniformly granulating the WC raw materials, and improving the sintering conditions, in particular. As shown in Fig. 6, both the S10 grade and S20 grade show fracture toughness values 1.2 times or higher than that of conventional materials.

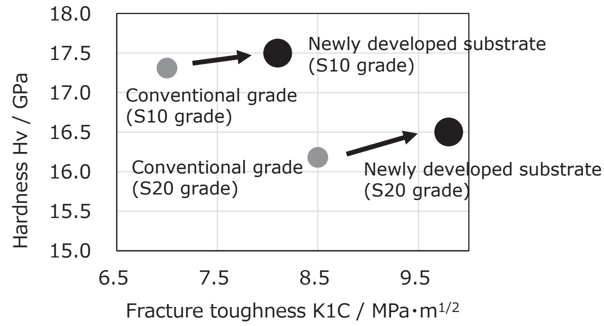

Fig. 6. Characteristic value of carbide substrate

3-3 Cutting performance of AC5015S and AC5025S

We commercialized AC5015S, which is derived from the combination of the AlTiSiN film and the S10 grade substrate, and AC5025S, which is derived from the combination of the AlTiSiN film and the S20 grade substrate.

The wear resistance test of Inconel 718 was conducted using AC5015S. The results are shown in Fig. 7. AC5015S demonstrated a tool life that is double or more that of conventional materials.

A similar evaluation was made on AC5015S by increasing the cutting speed to 70 m/min. The results showed that machining is possible for up to 13 minutes, achieving high efficiency machining that is double that of the conventional material.

The boundary fracture resistance test of Hastelloy*[4] was conducted using AC5025S. Figure 8 shows the results. AC5025S demonstrated notch wear resistance that is double that of the conventional material.

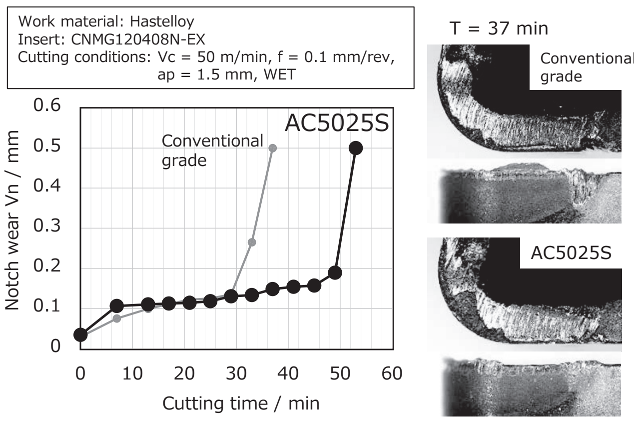

Fig. 8. Results of evaluation of cutting Hastelloy using AC5025S

4. Examples of Machining Using AC5015S and AC5025S

Figures 9 to 12 show examples of machining of heat-resistant alloys using AC5015S and AC5025S by different users.

The results of the machining of an aircraft part (Inconel 718) using AC5015S are shown in Fig. 9. The tool life of AC5015S was double that of the competitor's

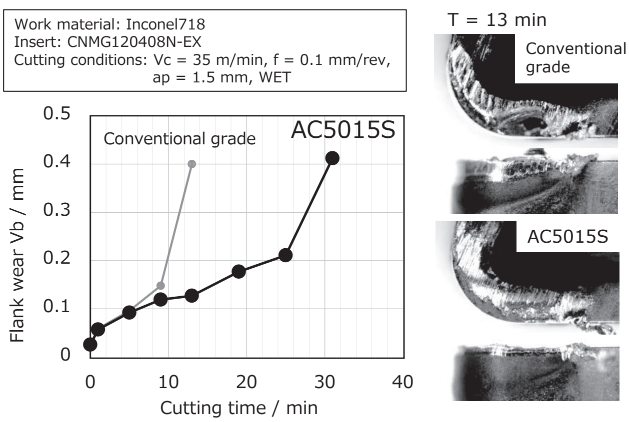

Fig. 7. Results of evaluation of cutting Inconel 718 using AC5015S

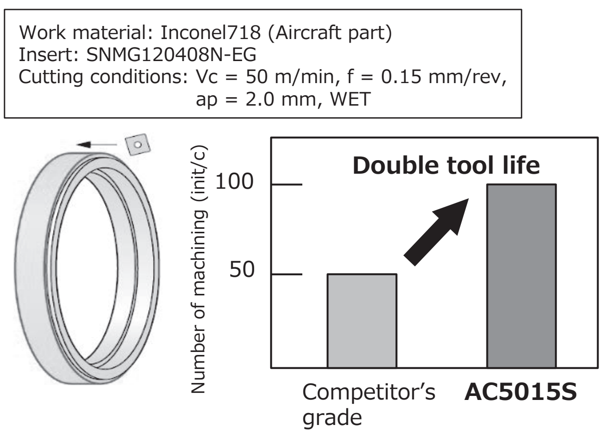

Fig. 9. Example of machining using AC5015S ①

product due to the excellent wear resistance.

Figure 10 shows the results of the machining of an automotive part (Inconel 713C) using AC5015S. Under the high-speed conditions (cutting speed: 100 m/min.), the tool life of AC5015S was double that of the conventional product.

The results of the machining of an aircraft part (Inconel 718) using AC5025S are presented in Fig. 11. The tool life of AC5025S was 1.7 times that of the conventional product. The damage after machining was negligible.

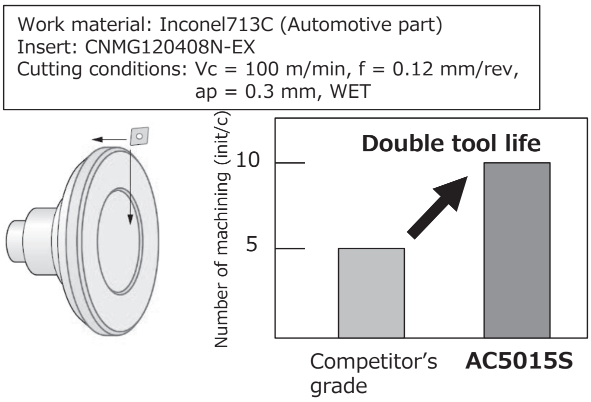

Fig. 10. Example of machining using AC5015S ②

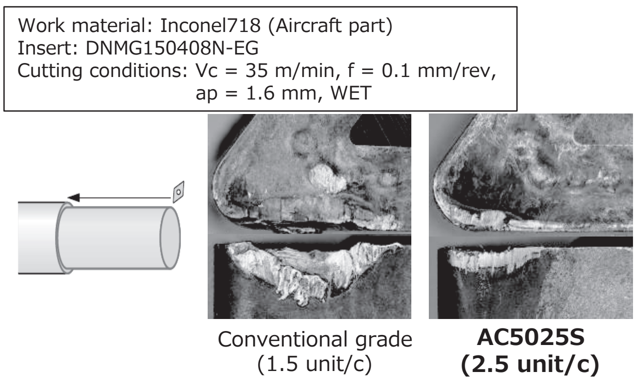

Fig. 11. Example of machining using AC5025S ①

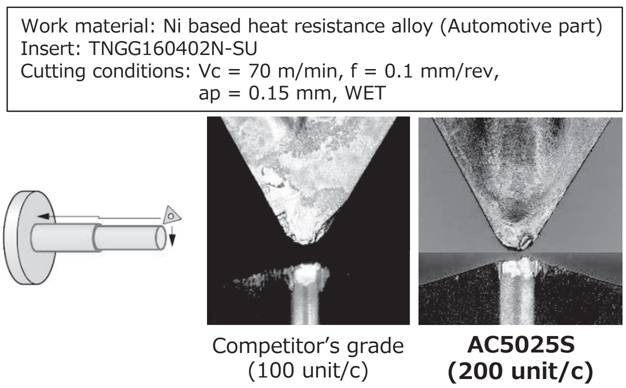

Fig. 12. Example of machining using AC5025S ②

Figure 12 shows an actual example of the machining of an automotive part (Ni-based heat-resistant alloy) using AC5025S. The tool life of AC5025S was double that of a competitor's product.

5. Conclusion

As discussed above, we developed a new PVD coating film with superb wear resistance and a new cemented carbide substrate with outstanding notch wear resistance, and applied them to AC5015S and AC5025S.

We succeeded in achieving stable performance and long tool life (more than double that of conventional materials). These two materials will contribute greatly to reducing the cost of machining and improving productivity in turning difficult-to-machine materials.

Technical Terms

*1 Physical vapor deposition (PVD): A target material is ionized by arc discharge or other means and reacted with a gas to allow the gas to deposit on the base material as a ceramic film.

*2 Inconel: A type of Ni-based heat-resistant alloy. It is a registered trademark of Special Metals Corporation.

*3 Energy dispersive X-ray spectrometry (EDX): A technique to measure elements that constitute an object and their concentration based on characteristic X-ray that is generated when an electron beam or X-ray is irradiated on an object.

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

Contributors
The lead author is indicated by an asterisk (*).

S. IMAMURA*
• Manager, Sumitomo Electric Hardmetal Corp.

K. TANAKA
• Assistant Manager, Hardmetal Division

S. MISUMI
• Sumitomo Electric Hardmetal Corp.

K. HIROSE
• Manager, Sumitomo Electric Hardmetal Corp.

H. FUKUI
• Assistant General Manager, Sumitomo Electric Hardmetal Corp.