New Coated Carbide Grades for Cast Iron Turning

Susumu OKUNO*, Hideaki KANAOKA, Satoshi ONO, Shinya IMAMURA, Kazuhiro HIROSE, and Haruyo FUKUI

Automotive components have increasingly complex designs and thin walls for weight reduction, and accordingly, high-strength, difficult-to-cut materials are used. Meanwhile, high-speed and high-efficiency machining is also required to reduce lead time. Under these circumstances, cutting tools need to have long tool life and stable performance. To satisfy these demands, the authors have developed the new coated carbide grades AC4010K and 4015K for cast iron turning. This paper describes their features and cutting performance.

Keywords: CVD, cutting tool, high-speed, high-efficiency, cast iron

1. Introduction

Indexable inserts used for cutting tools, which are made by coating the surface of cemented carbide with a hard ceramic film (coated grades), have better-balanced wear resistance and chipping resistance than other inserts. Because of such superior characteristics, coated grades have an increasing use rate and they currently account for 70% of all base materials of indexable inserts.[1] Coated grades are used in the cutting of various materials such as carbon steel, alloy steel, stainless steel, and cast iron. For each of these materials, various measures have been taken to reduce the environmental impact and improve resource efficiency. In the machining of automotive components made of cast iron, in particular, efforts have been made to reduce their weight and thereby minimize exhaust gas emissions and enhance fuel economy. These efforts have led to thinner walls and increasingly complicated component shapes. To give sufficient strength to these thin-walled components, conventional easy-to-cut gray cast iron (FC) has been replaced with high-strength, difficult-to-cut ductile cast iron (FCD). On the other hand, high-speed, high-efficiency machining is increasingly required due to the rising demand for cost reduction and improved performance of machine tools. Therefore, cast iron cutting tools are required to have high stability and a long tool life even under such severe requirements.

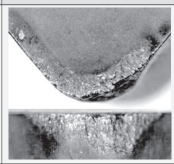
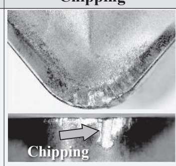
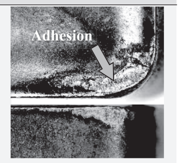
To meet the market needs described above, Sumitomo Electric Industries, Ltd. has developed and launched new coated grades AC4010K and AC4015K. The former grade ensures high-speed continuous turning of gray cast iron, while the latter enables stable turning with an extended tool life in general-purpose machining of mainly ductile cast iron.

This paper describes the details of the development of the new coated grades and their performance.

2. Development Target for AC4010K and AC4015K

Damage to coated grades in cast iron turning is roughly classified into three forms as shown in Table 1. Prior to the development of AC4010K and AC4015K, cutting tools that had been actually used in cast iron turning were collected and their damage was investigated with the aim of clarifying the characteristics required of these coated grades. The investigation results revealed that more than 70% of these cutting tools had reached their tool life due to chipping damage or the combination of chipping damage and wear damage that are shown in Table 1. Cutting tools had been damaged due to chipping wear regardless of the FC or FCD they machined. However, damage to the cutting tools used for turning FCD having higher strength was more conspicuous. It was concluded from the above investigation results that protecting cutting tools from chipping during turning would be the most important measure to extend their tool life. As a result, development target was set to increase the chipping resistance of new coated grades to 1.5 times or more that of conventional grades.

Table 1. Examples of Cutting Tool Damage in Cast Iron Turning and Cause of Damage

	Wear	Chipping	Adhesion
Example of damage			
Causes	Wear begins to rapidly progress immediately after the coated film is thinned as a result of rubbing against hard components. In particular, cutting tools often suffer this type of damage when machining FC at high speeds.	Cumulative fine chipping of the cutting edge ridge due to contact of the edge with fine undulations on the surface during intermittent or continuous machining.	Fine powder from soft components is pressed against the cutting tool's surface and sticks tightly to the surface. When separating from the tool's surface, the powder peels the coated film off the tool. In particular, cutting tools often suffer this type of damage when machining FCD.
Required Properties	Increased hardness and thickness of coated film	Increased hardness and adhesion force of coated film	Increased adhesion force of coated film and smoother film surface

The damage investigation results also revealed that some cutting tools, when used for turning FC at high speeds of more than v_c = 500 m/min, had rapidly reduced the coated film thickness on the cutting face due to scraping by chips and had reached their tool life. To reduce the tool damage caused by the above mechanism, it would be effective to increase the thickness of the alumina (Al_2O_3) film, one of the films coated on tool surfaces to resist heat. However, increasing the thickness of the alumina film was expected to deteriorate the chipping resistance of the cutting tool. After various discussions, we concluded that it is difficult to give mutually contradictory characteristics to a single coated grade and decided on two types of coated grades AC4010K and AC4015K. We aimed to provide AC4010K with the capability of turning FC at a high speed of more than v_c = 500 m/min with wear resistance two times or more that of the comparable conventional grade while maintaining high chipping resistance. For AC4015K, we aimed to provide it with the capability of general purpose turning of FCD and other materials with chipping resistance 1.5 times or more that of the comparable conventional grade while maintaining the same level of wear resistance.

3. Features of AC4010K and AC4015K

Improving the chipping resistance of both AC4010K and AC4015K was crucial for accomplishing the development targets. Increasing the mechanical strength and adhesion strength of the coated films was essential to meeting the above need. We successfully overcame the above challenge by developing the following three technologies:

3-1 Suppressing crack propagation in coated film

Ceramic films on the surfaces of AC4010K and AC4015K are formed by the chemical vapor deposition (CVD).*[1] In this process, the cutting tools are placed in a vacuum furnace maintained at approximately 1,000°C. After ceramic films are formed, the tools are cooled to room temperature. In this cooling process, residual tensile stress is occurred in coated ceramic film because of the difference in the thermal expansion coefficient between the ceramic film and cemented carbide. Once a fine crack is generated in the coated film due to machining impact force or other cause, the residual tensile stress in the coated film helps the crack to propagate and deteriorate the chipping resistance of the cutting tool. Sumitomo Electric had already acquired a technology to reduce residual tensile stress in or impart compressive stress to a coated film by subjecting its surface to a unique treatment (surface treatment) . This technology is used for conventional cast iron turning grades to impart compressive stress to them. However, as imparting the conventional level of compressive stress to coated films would be insufficient to meet user requirements, we reviewed and improved the conventional stress imparting process and equipment. The improved process and equipment enable the application of compressive stress of 1 GPa, which is two times the conventionally imparted stress, to Al_2O_3 films (Fig. 1).

A cutting performance evaluation test was carried out to verify the effectiveness of imparting compressive stress to a coated film. In the evaluation test, FCD450 was intermittently cut at a speed of v_c = 450 m/min under the conditions of 1.5 mm in the depth of cut (a_p) and 0.3 mm/rev in feed rate (f). The tool life was defined as the actual length of time until the tool became unusable as a result of intensive chipping-off of the cutting edge. The damaged states of the conventional and newly developed tools after cutting the test materials for 240 seconds are shown in Fig. 1. After 240 seconds of cutting, the tool that had been treated by the conventional process was largely chipped off at its edge. In contrast, the tool to which compressive stress of 1 GPa had been imparted by the new process were able to be continuously used even after 240 seconds, though the cutting edge was slightly chipped off, and finally reached its tool life when used for 420 seconds. The new tool after use for 240 seconds was visually examined in detail. Many cracks, which were estimated to have been generated during turning, were found on the tool surface. However, the propagation of these cracks was prevented by the high compressive stress that had been imparted by the new process, verifying that the new process is more effective in reducing the severity of tool damage than the conventional process.

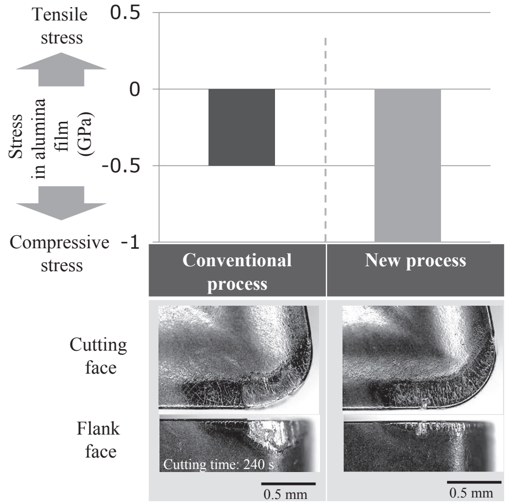


Fig. 1. Compressive Stress in Alumina Film and Chipping Resistance

3-2 Improving the strength of coated film by controlling the growth orientation of Al_2O_3 crystallite

Figure 2 shows the cross-sectional structure of a ceramic film that was coated on a cemented carbide base material by the CVD process. The structure usually consists of Al_2O_3 and TiCN layers. The Al_2O_3 layer is formed on the outer side of the ceramic film and insulates heat, while the TiCN layer is formed on the inner side of the ceramic film and resists wear. It is already known that, when turning FC at a high speed of more than v_c = 500 m/min, thermal damage to the cutting tool can be suppressed by thickly forming Al_2O_3 film, a heat insulation layer. However, the strength of the film decreases as its thickness increases. We prepared a cutting tool by subjecting it to a specific heat treatment after coating with Al_2O_3 film more thickly than a conventional film, and evaluated the machinability of this tool by intermittently cutting FC250.

In the test, the coated film separated from the cutting face and subsequently the flank face of this tool was damaged as shown in the lower part of Fig. 2. As a result of detailed visual examination of the cutting tool before it was damaged due to the separation of the coated film from the cutting face, it was confirmed that the Al_2O_3 film had begun to locally break and that subsequent propagation of this breakage led to the tool becoming damaged due to the separation of the coated film. The cause of the tool damage due to the separation of coated film was analyzed as follows. In an Al_2O_3 film that is formed by the conventional coating process, the constituent particles grow in random directions as schematically illustrated in Fig. 2. Therefore, the constituent particles are separated by the shearing stress that is produced when chips scrape the surface. Based on the above analysis result, we developed an Al_2O_3 film with the Al_2O_3 crystallites arranged in parallel with the crystal face perpendicular to the chip shearing direction or in the c-axis direction perpendicular to the cross-section of the film. Various studies that were made on film formation parameters to control crystalline orientation have made it possible to orient more than 90% of Al_2O_3 crystallites in the c-axis direction. When a cutting tool coated with an Al_2O_3 film having newly oriented crystallites was used for intermittent turning of FC, damage to the tool attributable to the separation of film from the cutting face decreased dramatically as shown in the lower part of Fig. 2.

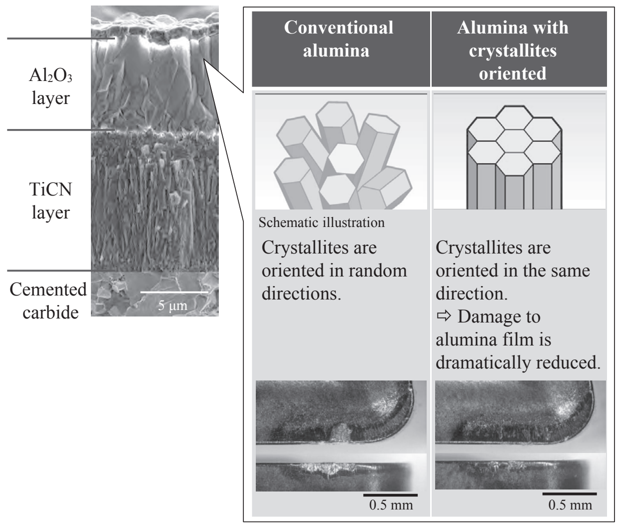


Fig. 2. Cross-sectional Structure of Film Coated on Cutting Tool and the Effect of Alumina Crystallite Orientation Control

3-3 Improving adhesion strength of coated film

To successfully develop AC4010K and AC4015K, we developed a technology for improving the adhesion strength of the coated film in addition to the technologies for improving the crack propagation resistance of the coated film by imparting compressive stress and enhancing the strength of the alumina film by controlling its Al_2O_3 crystallites. Described below is an example of adhesion strength improvement of coated film by minimizing the surface roughness of the base material. Figure 3 shows the cross-sectional structure of the edge of a base material that was subjected to a conventional honing process*[2] and the cross-sectional structure of a coated film that was subjected to the honing process newly introduced for AC4010K and AC4015K. This figure verifies that, when subjected to the new honing process, AC4010K and AC4015K reduce the surface roughness of the base material of the cutting edge to half that of a conventionally treated base material. In consequence, the smoothened base material surface reduces the surface roughness of the coated ceramic film. The result of an FC intermittent turning test is shown in the lower part of Fig. 3. This figure confirms that AC4010K and AC4015K reduce the surface roughness of the base material, thereby dramatically reducing the chipping damage of the cutting edge attributable to machining impact force.

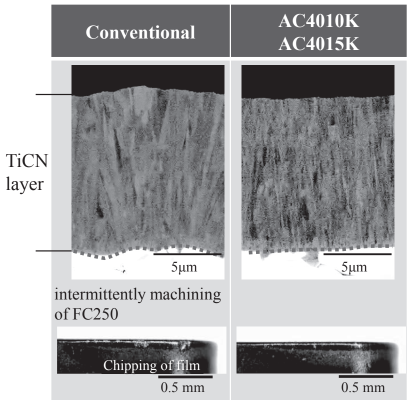


Fig. 3. Improvement of Film Adhesion Strength by Smoothening of Substrate

4. Cutting performance of AC4010K and AC4015K

Examples of practical turning of FC and FCD with AC4010K and AC4015K are shown in Figs. 4 and 5. Figure 4 compares a conventional insert and AC4010K used in the turning of FC250 brake discs under high-efficiency conditions of a maximum speed of 960 m/min and a maximum feed rate of 0.75 mm/rev. The conventional

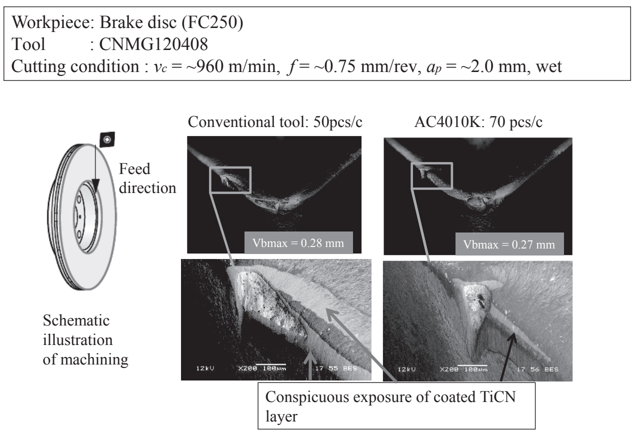


Fig. 4. Examples of FC250 Turning with AC4010K and Conventional tool

insert used for the same purpose reached its tool life when it machined 50 workpieces since it deteriorated the quality of machined surfaces due to the progress of wear and damage to the cut boundary portion by chipping. In contrast, AC4010K was able to machine 70 workpieces, 1.4 times the quantity achieved by the conventional insert. After both insets reached their tool lives, the damaged portions were examined on a scanning electron microscope. The result showed that AC4010K had limited chipping on the coated film in the boundary portion, thereby suppressing the exposure of cemented carbide even after machining more brake discs than the conventional insert. In addition, the thickened Al_2O_3 film suppressed the progress of fretting wear of the coated film and the exposure of the TiCN film used as the lower layer. As described above, AC4010K has improved chipping resistance and wear resistance in high-speed, high-efficiency machining of gray cast iron, thereby extending the tool life of cutting tools.

Figure 5 shows examples of turning the end faces of FCD500 gear casings. Since the surfaces of the workpieces were as-cast and rectangular, extremely complicated and intermittent turning operations were often required. The cutting edge of the conventional cutting tool was intensively chipped. Edges of some of the indexable inserts were lost and made the cutting tool unusable when it had machined 10 gear casings. In contrast, AC4015K did not suffer such chipping or damage and was able to be continuously used even after machining 1.2 times the quantity of gear casings. As discussed above, the superior chipping resistance of AC4015K ensures stable intermittent turning of FCD, which would be difficult with conventional grades.

Workpiece: Gear casing (FCD500)
Tool : CNMG120408
Cutting condition: v_c = 220 m/min, f = 0.35 mm/rev, a_p = 1.5 mm, wet

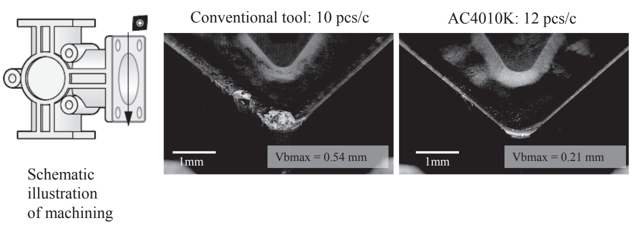


Fig. 5. Examples of FCD500 turning with AC4010K and conventional tool

5. Conclusion

We have developed technologies that are essential for improving the strength of coated films and succeeded in creating the new coated grades AC4010K and AC4015K. The former grade enables high-speed, high-efficiency continuous turning of FC and other materials, while the latter ensures stable truing with extended tool life in the general purpose turning of FCD and other materials. These two coated grades are expected to help users reduce machining costs and enhance productivity in a wide range of uses, from high-speed, high-efficiency continuous turning to intermittent turning regardless of the FC and FCD.

Technical Terms

＊1 Chemical vapor deposition (CVD): A method for depositing a ceramic film on a base material by the reaction of vapor phase chemicals.

＊2 Honing process: A process for rounding or slightly chamfering the cutting edges of a cutting tool.

Reference

(1) Monthly report of Japan Cemented Carbide Tool Manufacuturers' Association (2015)

Contributors

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

S. OKUNO*
• Assistant Manager, Hard Materials Development Department, Sumitomo Electric Hardmetal Corp.

H. KANAOKA
• Sumitomo Electric Carbide, Inc.

S. ONO
• Hard Materials Development Department, Sumitomo Electric Hardmetal Corp.

S. IMAMURA
• Group Manager, Hard Materials Development Department, Sumitomo Electric Hardmetal Corp.

K. HIROSE
• Group Manager, Global Marketing Department, Hardmetal Division

H. FUKUI
• Ph. D.
Assistant General Manager, Hard Materials Development Department, Sumitomo Electric Hardmetal Corp.