New Coated-Carbide Grade AC4125K for Cast Iron Turning

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Automotive components have complex designs and thin walls, for weight reduction. In recent years, such materials are becoming increasingly difficult to cut due to their high strength. Meanwhile, there has been a growing demand for high-speed and high-efficiency machining to reduce lead time. Under these circumstances, customers need cutting tools that have long tool life and stable cutting performance. To satisfy these demands, we have developed the new coated grade AC4125K for cast iron turning. This paper describes the features and cutting performance of AC4125K.

Keywords: cutting tool, cast iron, CVD, intermittent turning, visibility of used corner

1. Introduction

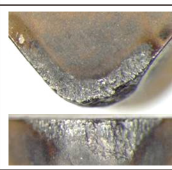
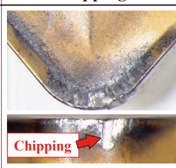
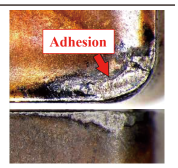
Indexable inserts, a typical cutting tool, are usually made from cemented carbide*1 coated with hard ceramics (coated grades). Due to their exceptional combination of wear resistance and resistance to chipping, coated grades are increasingly used and currently account for 70% of all materials used in indexable inserts.(1) Coated grades find applications in the cutting of various materials, including carbon steel, alloy steel, stainless steel, and cast iron. For each of these materials, numerous initiatives have been undertaken to minimize environmental impacts and efficiently utilize resources. In the machining of automotive components made from cast iron, there have been concerted efforts to reduce their weight, consequently, minimizing exhaust gas emissions and enhancing fuel economy. To achieve this objective, components must have thinner walls, resulting in having more complicated shapes. To provide sufficient strength to thin-walled components, high-strength ductile cast iron (Ferro casting ductile, or FCD material), which has poor machinability, is used in an increasing number of cases. In particular, FCD materials used for differential cases are becoming stronger and more difficult to machine. Thus, machinability drops significantly in terms of both shapes and types of materials. On the other hand, at the processing site, high-speed, high-efficiency machining is increasingly required due to the rising demand for cost reduction and improved performance of machine tools. Therefore, even under such harsh cutting conditions, cast iron machining tools are required to achieve high stability and a long tool life.

To meet such market needs, Sumitomo Electric Industries, Ltd. has successfully developed new coated grades AC4125K that achieve superior stability and extended tool life in intermittent machining of ductile cast iron and launched them in December 2023. This paper describes the details of its development process and performance.

2. Development Target for AC4125K

The damage to coated grades in cast iron turning can be classified into three forms, as shown in Table 1. Prior to the development of AC4125K, we have collected cutting tools that had been used in cast iron turning and investigated their damage to determine the necessary characteristics of these coated grades. As a result, it was revealed that approximately over 70% of these cutting tools had reached the limit of their tool life due to chipping damage or the combination of chipping damage and wear progression as indicated in Table 1. Such damage with chipping occurred regardless of the material used, whether it was gray cast iron (FC material) or ductile cast iron (FCD material), but it was more noticeable in the processing of high-strength FCD material. Therefore, in order to enhance their tool life in cast iron machining, it was determined that preventing from chipping during turning would be the most important factor. As a result, the development target was set to increase the chipping resistance of new coated grades AC4125K to 150% or more than that of conventional grades.

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

	Wear	Chipping	Adhesion
Example of damage			
Causes	Once the coated film is thinned due to rubbing against hard components, wear starts to progress rapidly. This type of damage is commonly observed in cutting tools when machining FC at high speeds.	The cutting edge ridge can experience cumulative fine chipping as a result of contact with fine undulations on the surface during intermittent or continuous machining.	Fine powder from soft components can be pressed against the cutting tool's surface, adhering tightly to it. When this powder separates from the surface, it can peel off the coated film on the tool. This type of damage is commonly 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

3. Advantages and Cutting Performance of AC4125K

To achieve the development goal of AC4125K, it is crucial to enhance its chipping resistance. Improvements in chipping resistance can be achieved by increasing the strength of the coating film and enhancing its adhesion. In the development of AC4125K, three new technologies were developed to accomplish higher coating film strength, improved adhesion strength, and enhanced visibility.

3-1 Suppression of crack propagation in coated film

The ceramic films on the surfaces of AC4000K series, including AC4125K, are formed using the chemical vapor deposition (CVD)*2 process. In this process, the cutting tools are placed in a vacuum furnace maintained at approximately 1,000°C. After the ceramic films are coated, the tools are cooled to room temperature. During the cooling process, residual tensile stress*3 occurs in the coated ceramic film due to 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 causes, the residual tensile stress in the coated film facilitates the propagation of the crack, deteriorating the chipping resistance of the cutting tool. Sumitomo Electric developed a technology to reduce residual tensile stress in the coated film or to introduce compressive stress through a unique surface treatment. This technology has been applied to conventional cast iron turning grades to introduce compressive stress. In response to user requirements, the conventional process and equipment for introducing compressive stress to coated films were reviewed and improved. The improved process and equipment allow for the application of a compressive stress level of 1 GPa to Al_2O_3 films, twice the stress previously imparted, as shown in Fig. 1. A cutting performance evaluation test was conducted to verify the effectiveness of imparting compressive stress to a coated film. In the test, FCD450 was intermittently cut at a speed of vc = 450 m/min under the conditions of 1.5 mm in the depth of cut (ap) and 0.3 mm/rev in feed rate (f). The tool life was defined as the measured duration until the cutting tool became unusable due to intensive chipping of the cutting edge. The damaged states of the conventional and 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 was 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 developed tool after use for 240 seconds was visually examined in detail. Numerous cracks were found on the tool surface, likely generated during the turning. However, the propagation of the cracks was prevented by the high compressive stress imparted by the new process, verifying that the new process is more effective in reducing the severity of tool damage than the conventional process.

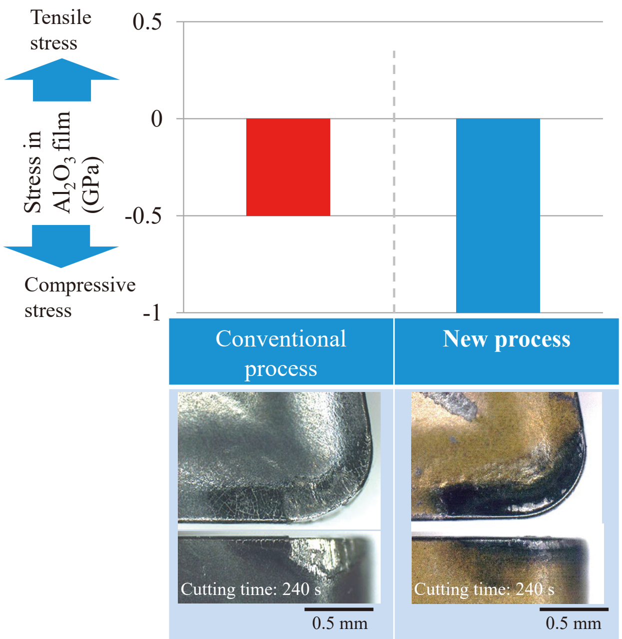


Fig. 1. Compressive Stress in Al_2O_3 Films and Chipping Resistance

3-2 Enhancement of coated film by controlling fine growth orientation of Al_2O_3 crystallites

Figure 2 shows the cross-sectional microstructure of a ceramic film coated on a substrate using the CVD process. It is common for the structure to consist of a two-layer film, with an Al_2O_3 film serving as the heat-insulating layer on top and a TiCN film serving as the wear-resistant layer at the bottom. It is known that in high-speed turning of FC, with cutting speeds exceeding vc = 500 m/min, thermal damage can be mitigated by using a thicker Al_2O_3 film as the insulating layer, but this may also cause delamination. In this study, a cutting tool was prepared by subjecting it to a specific heat treatment after coating it with a thicker Al_2O_3 film compared to the conventional films, and its machinability was evaluated by intermittent cutting of FC250 material. During the test, the coated film peeled off from the rake face leading to damage on the flank face of the tool. Upon detailed observation of the cutting tool before it was damaged by film separation, it was found that the Al_2O_3 film experienced local breakage, which subsequently propagated and caused tool damage due to film separation. The analysis of the cause of tool damage due to film peeling is as follows: in the conventional coating process, the Al_2O_3 film is formed with constituent particles growing in random directions, as schematically depicted in Fig. 2. As a result, shearing stress generated by chip

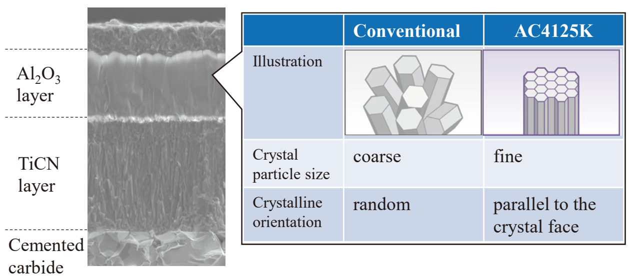


Fig. 2. Cross-sectional Structure of Film Coated on Cutting Tool and the Features of Al_2O_3 Crystallite

scraping can cause separation between the constituent particles. Based on this analysis, we developed an Al_2O_3 film where the Al_2O_3 crystallites are aligned perpendicular to the direction of chip shearing or in the c-axis direction perpendicular to the film's cross-section. By studying various coating parameters, it became possible to control the crystalline orientation of the Al_2O_3 film. The studies achieved an orientation of over 90% of the Al_2O_3 crystallites in the c-axis direction. When a cutting tool coated with an Al_2O_3 film containing these newly oriented crystallites was used in intermittent turning of FC, the tool damage caused by film separation significantly decreased.

In the case of AC4125K, the grain size of the Al_2O_3 crystallites has been optimized to achieve a fine, dense, and uniform structure. This refinement significantly suppresses crack propagation within the Al_2O_3 film, resulting in exceptional resistance to chipping. Through various investigations of coating parameters, it was possible to refine the grain size of the Al_2O_3 crystallites while still maintaining over 90% of them oriented along the c-axis, which is crucial for performance. To evaluate the cutting performance, tests were conducted on intermittent FCD450 material under the specified conditions: a cutting speed (vc) of 400 m/min, a feed rate (f) of 0.3 mm/rev, an axial depth of cut (ap) of 1.5 mm, and the use of cutting fluid (wet). The tool life in the evaluation was determined by the number of impacts before chipping occurred at the cutting-edge ridge. As shown in Fig. 3, a significant reduction in chipping was observed compared to the conventional grade, leading to an improvement in the overall service life of the tool.

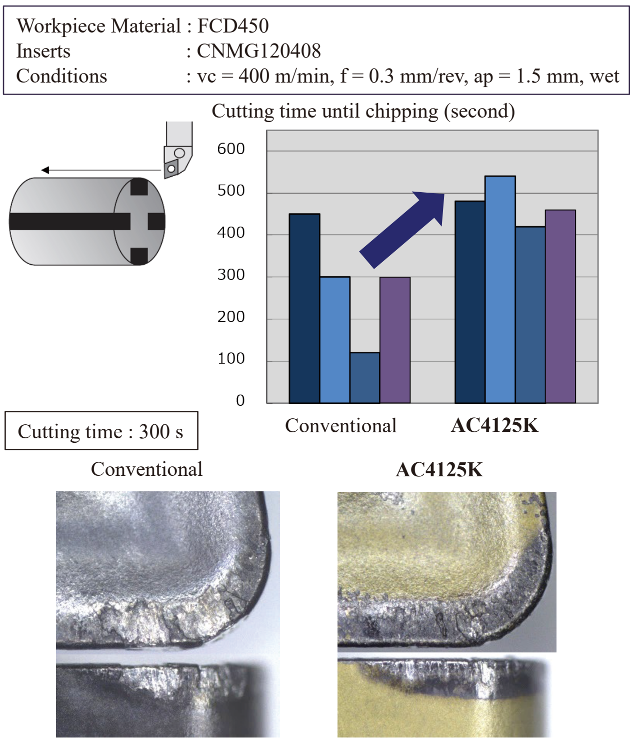


Fig. 3. Comparison of AC4125K and Conventional in Chipping Resistance Evaluation

3-3 Improved visibility by depositing the corner identification layer

In addition to the aforementioned developments, we have improved the visibility of the insert corner by depositing an identification layer.

For steel turning grades, a gold-colored layer is deposited on the surface of insert to improve visibility. However, for cast iron turning grades, as shown in Fig. 4, a black-colored Al_2O_3 film was generally used as the surface layer because thermal cracks can occur more easily in the gold-colored layer, leading to a decrease in cutting performance.

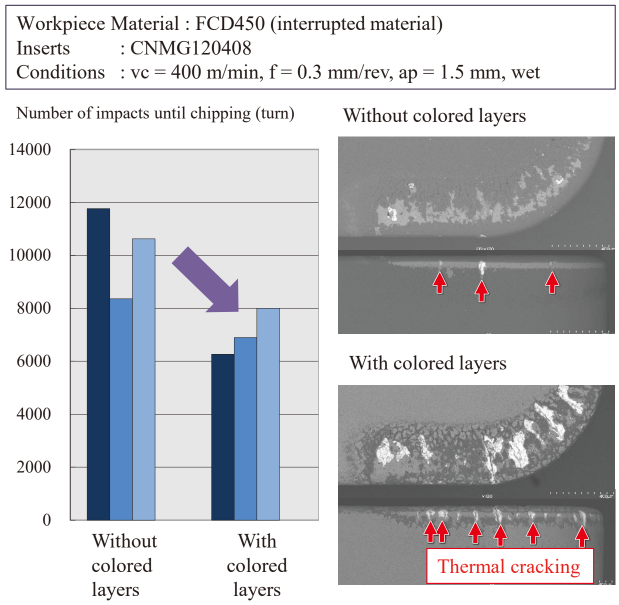


Fig. 4. The Evaluation Results of the Effect of Colored-layers on Cutting Performance

However, feedback has indicated that the black appearance makes it difficult to distinguish whether the cutting corner has been used or not. As a result, they mistakenly discard inserts with unused corners or misinterpret used corners. Therefore, we have developed a coloring process that provides a gold-colored layer while maintaining the cutting performance.

Photo 1 shows the used corners of the conventional grade and AC4125K. The improved visibility helps to prevent the disposal of inserts with unused corners and the

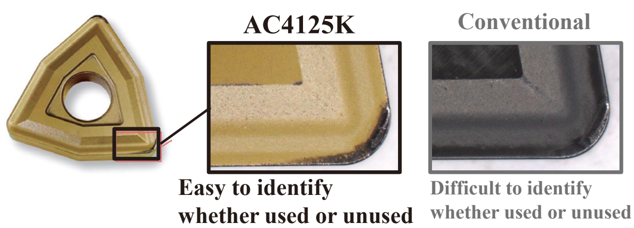


Photo 1. Used Corners of Conventional Grade and AC4125K

misinterpretation of used corners. This, in turn, increases the number of times a tool can be utilized, resulting in an extension of tool life.

4. Cutting performance of AC4125K

Figure 5 illustrates examples of practical machining of FCD differential cases. Due to the scale surface and complex shape of the workpieces, machining operations often require intermittent and complicated turning.

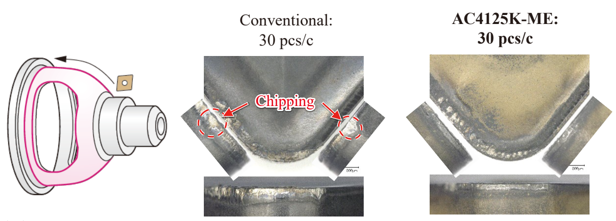
In case (a), the cutting edge of the conventional grade suffered severe chipping after machining 30 units of differential gears, resulting in the loss of some edges and rendering the inserts unusable. Conversely, the cutting edge of AC4125K did not experience such chipping or damage after machining the same number of differential gears, remaining in a condition suitable for continued use. Even after machining 30 units of differential gears, the cutting edge still retained its usability.

In case (b), the cutting edge of the conventional grade suffered severe chipping after machining 8 units of wheel hubs, resulting in the loss of some edges and rendering the inserts unusable. In contrast, the cutting edge of AC4125K did not experience such chipping or damage even after machining 10 units of wheel hubs, remaining in a condition suitable for continued use.

As discussed above, the superior chipping resistance of AC4125K ensures stable intermittent turning of FCD, which would be difficult to achieve with conventional grades.

(a)

Workpiece Material : Differential case (FCD450) (interrupted processing)
Inserts : CNMG120412
Conditions : vc = 150 m/min, f = 0.2-0.3 mm/rev, ap = 2.0 mm, wet



(b)

Workpiece Material : Wheel hub (FCD500) (interrupted processing)
Inserts : DNMG150608
Conditions : vc = 200-300 m/min, f = 0.5 mm/rev, ap = 0.5 mm, wet

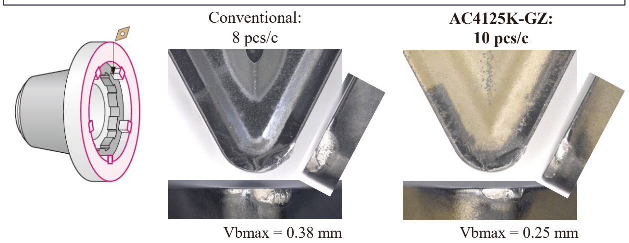


Fig. 5. Application Examples of AC4125K

5. Conclusion

The new coated grade AC4125K, enhanced with technologies to improve the strength of coated films, achieves high levels of wear and chipping resistance. Additionally, the application of a gold-colored coating has significantly improved visibility, making tool management easier and contributing to reduced machining costs for customers. The addition of AC4125K to the AC4000K series expands the range of machining options available for cast iron turning. This advancement is expected to help users reduce machining costs and improve production efficiency.

Technical Terms

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

*2 Chemical vapor deposition (CVD): A method of depositing ceramics on the surface of a substrate using a chemical reaction.

*3 Residual tensile stress: Tensile force that remains in an object after processes such as heat treatment. Residual tensile stress in a coated film reduces its strength, while a force in the opposite direction is called compressive residual stress.

Reference

(1) S. Okuno et al, "New Coated Carbide Grade for Cast Iron Turning," SEI TECHNICAL REVIEW No.85, pp.44-47 (2017)

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