Coated-Carbide Grades AC8015P, AC8025P, and AC8035P for Steel Turning

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To lessen the environmental burden, lead-free, difficult-to-cut materials are increasingly used and high-efficiency dry turning is becoming popular in the automotive industry. Under these circumstances, cutting tools need to have long tool life and offer stable performance. To satisfy these demands, we have developed the new coated-carbide grades AC8015P, AC8025P, and AC8035P for steel turning. This paper describes the features and cutting performance of these products.

Keywords: CVD, cutting tool, steel turning

1. Introduction

Indexable inserts for cutting tools are made of cemented carbide coated with a hard ceramic film and called coated grades. These grades have a better balance of wear resistance and chipping resistance than other inserts.

The ISO513:2004 standard categorizes the materials of items subject to cutting with coated grades (hereafter, such items are referred to as “the work” and the work’s material is referred to as “the workpiece material”) into six types: steel, stainless steel, cast iron, non-ferrous metal, thermal-resistant alloys, and hardened steel. Out of these six workpiece materials, steel forms the largest group, containing a range of variations such as carbon steel, alloy steel, and cast steel. Even though these materials are categorized under “steel,” the machinability of each material varies. For example, the hardness of carbon steel varies depending on the quantity of carbon contained, and the ductility of alloy steel differs depending on quantity of the added elements. Thus, cutting tools for steel work must be able to cope with a wide range of material characteristics. Also, a range of environmental protection measures have recently been introduced to the cutting process, such as adoption of lead-free alloy workpiece materials, and dry processing, which does not use cutting oil in order to reduce waste fluid processing. However, such pro-environmental measures tend to increase the burden on the cutting tools---lead-free materials degrade workability and dry processing increases processing heat---although the cutting tools are required to perform equally or even better under such increasingly demanding conditions. Additionally, it is expected that the Internet of Things (IoT) will create rapid advances in automation of steel turning, reducing or even eliminating human involvement. This means that cutting tools are required to have an even longer stable life than previously in order to avoid any sudden problems during steel turning that would require human intervention.

Sumitomo Electric Industries, Ltd. has a wide range of expertise in steel turning, and has recently developed and commenced sales of a steel cutting insert series that can respond to the above demands. The series includes a high-speed cutting insert, AC8015P, a standard insert, AC8025P, and an intermittent cutting insert, AC8035P. This paper describes the details of the development of the new coated grades and their performance.

2. Development Target for AC8015P, AC8025P, and AC8035P

Figure 1 shows a grade map of our products for steel turning. The coated carbide series includes three grades for steel turning. The AC8015P has a high wear resistance, and is therefore suitable for high-speed and continuous turning. The AC8025P widely covers continuous turning and interrupted turning and is thus used for general purposes. The AC8035P has a high strength and fracture resistance and is therefore suitable for heavy and interrupted turning.

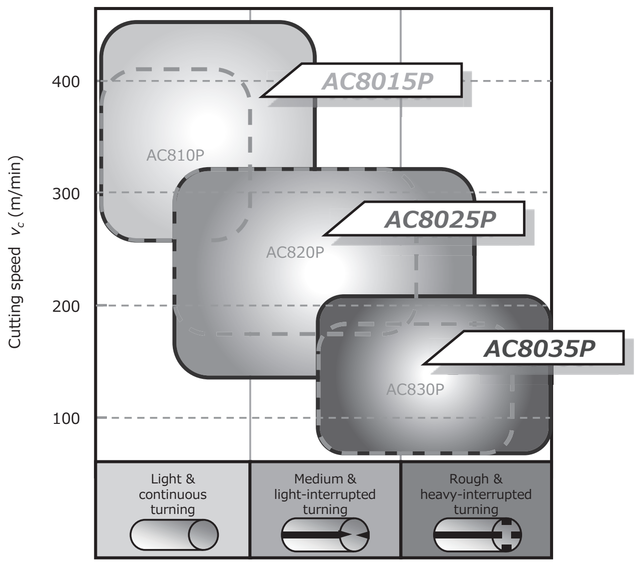


Fig. 1. Application areas of AC8015P, AC8025P, and AC8035P

2-1 Development target of the AC8015P, a grade for high-speed and continuous turning

In order to clarify the development target of our new grade for high-speed and continuous turning, we collected the used inserts made from the conventional AC810P grades from our customers and investigated the damage on the cutting edges. We have revealed that the main damage was crater wear (Fig. 2). Crater wear is caused mainly by chip flow on the rake face during turning. Extension of crater wear leads to poor chip control and sometimes breakage since the toughness at the cutting edge is reduced. Based on this investigation, we set our development target of 2 times higher resistance against crater wear compared with that of conventional grades.

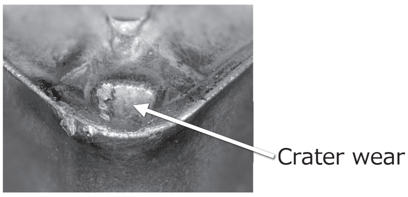


Fig. 2. Typical damage of AC810P (crater wear)

2-2 Development target of the AC8025P, a general purpose grade

In order to clarify the development target of our new general grade, we collected the used inserts made from the conventional AC820P grades from our customers and investigated the damage on the cutting edges. The general grades cover most steel turning operations, in which the type of cutting can be either continuous or interrupted at a wide range of cutting speed between 150 to 300 m/min. Because of this, the damage to the used inserts was a mix of various types. However, after separating and categorizing the types of damage, we revealed that the main damage was related to the expansion of chipping. Chipping can be divided into two types. One is chipping caused by impacts that occur repeatedly during interrupted turning, and the other is caused by the peeling of built-up edges generated through the adhesion of the workpiece material. The latter type of chipping (Fig. 3) may become an obstacle to automation with turning, as the adhesion accumulates and falls off at random intervals.

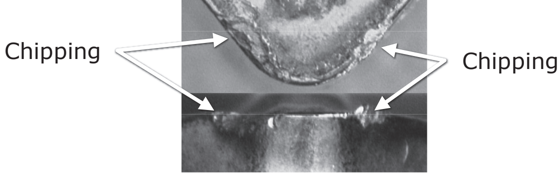


Fig. 3. Typical damage of AC820P (Chipping)

Also, the accumulated adhesion degrades finished surface precision even if not actually causing any chipping. For this reason, the development target of the new grade for general purposes was set to twice the resistance against chipping compared with that of the conventional grade, in order to further increase cutting quality stability.

2-3 Development target of the AC8035P, a grade for heavy and interrupted turning

In order to clarify the developmental target of our new grade for heavy and interrupted turning, we collected the used inserts made from the conventional AC830P grades from our customers and investigated the damage on the cutting edges. We have revealed that the main damage was related to fracture (Fig. 4). Fracture is the loss of a large part of the cutting edge due to the impacts repeatedly caused by interrupted turning. As a result, tool life varies. To address this issue, the development target of our new grade for heavy and interrupted turning was set to achieve twice fracture resistance compared with that of the conventional grade.

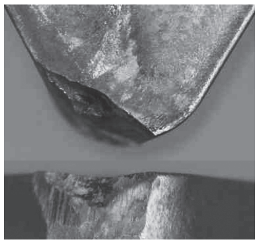


Fig. 4. Typical damage of AC830P (fracture)

3. Features of the AC8015P, AC8025P, and AC8035P

3-1 Features of the AC8015P: Control of alumina crystal orientation

Figure 5 shows the cross-sectional structure of a ceramic film that covers a cemented carbide base material by the chemical vapor deposition (CVD)*[1] 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. In high-speed steel turning, the progress of crater wear can be suppressed by thickly forming the Al_2O_3 film, a heat insulation layer. However, the strength of the film decreases as its thickness increases. In order to understand the deterioration mechanism concerning the coating strength derived from the thickening of the coating, we made detailed section view observations to follow the progress of the crater wear using field-emission scanning electron microscope (FE-SEM).*[2] Such observations revealed that the damage to the rake face with the thick coating was caused by not only heat but also the Al_2O_3 crystallite being scraped off from the coating. This is because when chip rubs against the rake face, the coating partially falls away due to the shear stress generated by the rubbing. We made an assumption that this fracture occurs due to the disorientation of the Al_2O_3 crystallites that form the coating, as shown in the model diagram at the bottom of Fig. 5. Based on the above analysis result, we developed a film with 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 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. Table 1 shows a comparison of cutting performance during high-speed turning of the bearing steel between the AC8015P, which uses the newly developed orientation-aligned crystalline alumina coating, and a conventional grade. In the conventional grade, crater wear has extended significantly on the rake face after turning for only 14 minutes. On the other hand, the extension of crater wear on the AC8015P during the same period of time was very small and it took 29 minutes to produce the same level of wear, which was more than twice the duration compared to that of the conventional grade. These observations thus concluded that the usage of oriented alumina in the AC8015P achieves more than twice the resistance against the crater wear compared with that of the conventional grade.

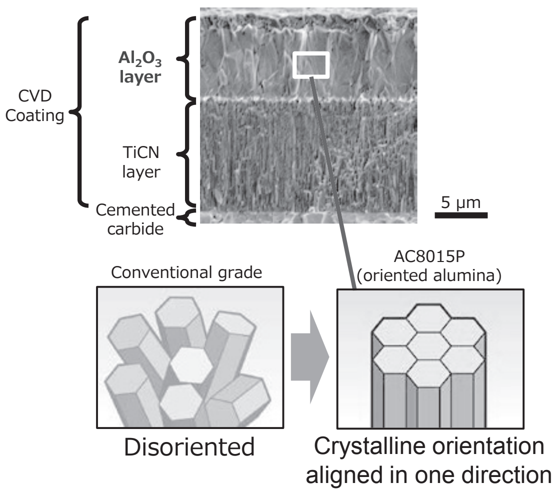
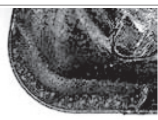
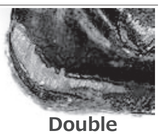


Fig. 5. Model diagram of AC8015P alumina crystalline structure

Table 1. Evaluation results on crater wear resistance

	2 min	14 min	29 min
Conventional grade		 Significant crater wear	
AC8015P			 Double the tool life

【Workpiece material】 SUJ2 Round bar
【Insert】 CNMG120408N-GU
【Cutting condition】 Vc=300 m/min, f=0.30 mm/rev, a_p=1.5 mm, wet

3-2 Features of the AC8025P: Surface smoothing

The outer surface of inserts with the ceramic coating applied using the CVD method is often coated with a titanium (Ti-based) ceramic layer. This outer layer indicates which corner of the insert has been used. For this reason, the tool surface has a minute roughness from the vapor deposited ceramic particles, as show in Fig. 6 (a). Additionally, the Ti-based coating has a high affinity with the workpiece materials. Therefore, the adhesion of workpiece materials on the cutting edge can easily occur in combination with the heat generated from contacting the work during turning, leading to the occurrence of chipping. The AC8025P was also covered with a CVD-based ceramic coating and Ti-based coating, but we removed the Ti-based coating around the cutting edge and smoothed the outer surface using a special mechanical treatment (Fig. 6 (b)). Through this mechanical treatment, the alumina coating, which is more chemically stable, is exposed on the cutting edge surface, while the surface roughness (Ra) has been reduced to one-tenth that of the conventional grade. This in turn reduces the friction heating generated from the rubbing of the chip, significantly lessening the generation of adhesion.

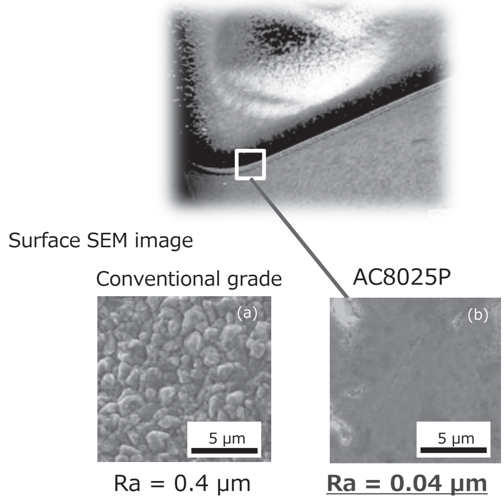
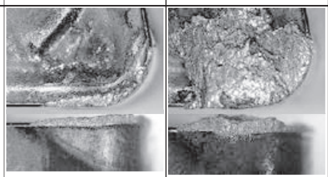
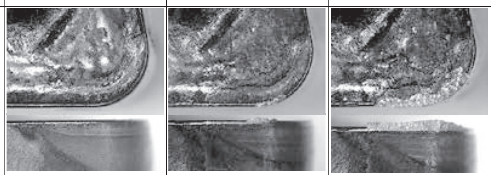


Fig. 6. Cutting edge surface structure of AC8025P

Table 2 shows a comparison of the progress of damage caused by adhesion during turning alloy steel (SCM415) between the AC8025P, with its surface smoothing treatment, and a conventional grade. The workpiece material had already built up at the cutting edge of the conventional grade after turning for two minutes, but hardly any buildup was observed at the cutting edge of the AC8025P. When we continued turning, a significant adhesion was formed at the cutting edge of the conventional grade and chipping occurred after turning for 70 minutes. On the other hand, the buildup on the AC8025P during the same time period was still relatively small. Further cutting work was continued on the AC8025P. At the 120 minute point there was still no chipping and cutting could continue. Thanks to the surface smoothing treatment, the AC8025P achieved more than twice the resistance against chipping compared with that of the conventional grade.

Table 2. Evaluation results on chipping resistance

	2 min	70 min	120 min
Conventional grade	 Adhesion occurs	Fracture	
AC8025P	 Small adhesion		Cutting can continue

【Workpiece material】 SCM415 Round bar
【Insert】 CNMG120408N-GU
【Cutting condition】 Vc=100-300 m/min, f=0.30 mm/rev, a_p=1.5 mm, wet

3-3 Features of the AC8035P: Control of residual stress in coating

In the CVD process, 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 fracture 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 grades for heavy and interrupted turning to impart compressive stress to the Al_2O_3 layer. 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. As a result, we established a method to provide an even higher compressive stress in the upper Al_2O_3 layer than that of the conventional method, as well as reducing the tensile stress in the lower TiCN layer by 90%, as shown in Fig. 7.

Figure 8 is a summary of a comparison of fracture resistance between the AC8035P and the conventional grade during interrupted turning of alloy steel (SCM435). When the feed rate f is increased step-by-step from 0.2 mm/rev to 0.3 mm/rev while the cutting speed is fixed, we counted the number of impacts undergone until a fracture occurred. Under the conditions indicated with a circle at the top of the bar in Fig. 8, the cutting edge didn't fracture even after undergoing 500 impact occurrences and cutting could be continued with the same insert. At f = 0.2 mm/rev, neither the conventional grade nor the AC8035P fractured. After that, the feed rate was increased to f = 0.25 mm/rev and then to 0.3 mm/rev. At f = 0.25 mm/rev, the conventional grade fractured after some 300 impacts, and the same grade fractured as soon as it came into contact with the work at f = 0.3 mm/rev. On the other hand, the AC8035P showed no fracturing at the cutting edge even after 500 impacts under any feed rate conditions and could continue cutting. Thus, the AC8035P realizes more than twice the fracture resistance compared with that of the conventional grade thanks to the significant reduction of residual tensile stress in the TiCN layer.

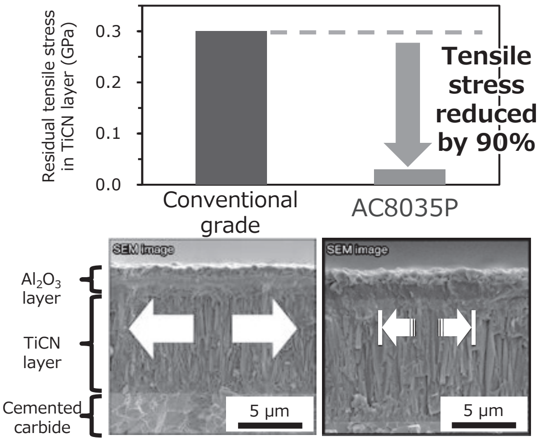


Fig. 7. Status of AC8035P tensile stress

【Workpiece material】 SCM435 Interrupted bar
【Insert】 CNMG120408N-GU
【Cutting condition】 Vc=160 m/min, f=0.20-0.30 mm/rev, a_p=2.0 mm, dry

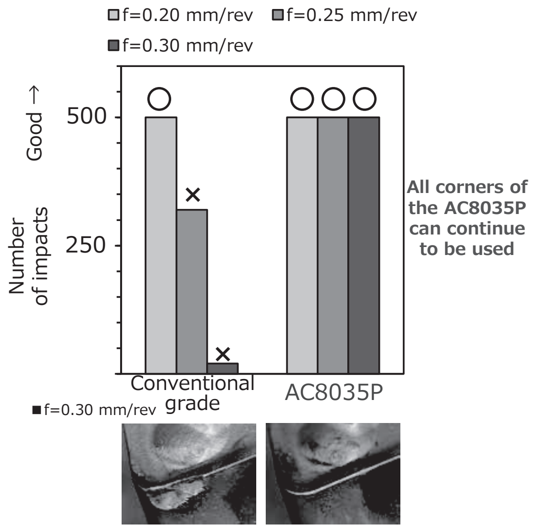


Fig. 8. Evaluation results on fracture resistance

4. Application examples of the AC8015P, AC8025P, and AC8035P

Application examples of alloy steel and carbon steel using the AC8015P, AC8025P, and AC8035P are shown in Figs. 9, 10, and 11, respectively.

Figure 9 shows an application example of the AC8015P. This is the turning of a ring gear (workpiece material: SCM435H) at a maximum cutting speed of Vc 260 m/min and a maximum feed rate of 0.4 mm/rev, which is a high-speed and high-feed turning. Damage to the rake face of the AC8015P was reduced due to the excellent crater wear resistance provided by the oriented alumina crystal, even after cutting 150 pieces/c, which is 1.5 times greater durability compared with that of the conventional grade. The case of turning a gear (workpiece material: SCM421) is a comparison with a competitors' insert. In this example also, the AC8015P, with its excellent crater wear resistance, showed 1.5 times greater durability than that of the competitors' insert under the same conditions.

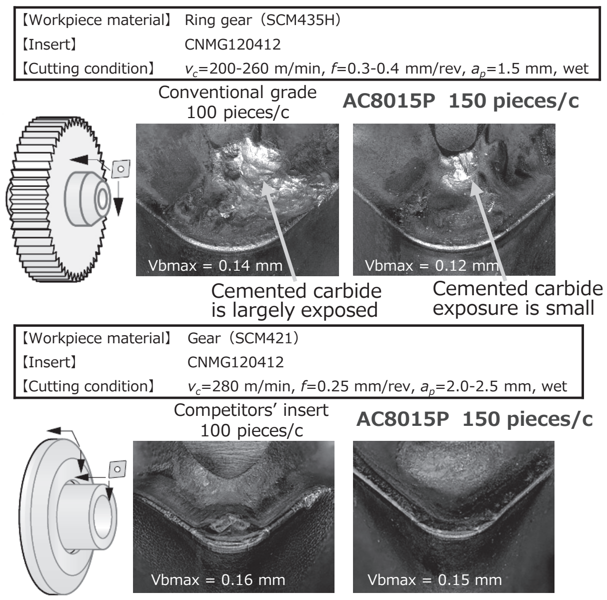


Fig. 9. Application example of AC8015P

Figure 10 shows an application example of the AC8025P. This is an example of continuous turning of low-alloy steel (SCM415), during which adhesion can easily be formed. When comparing the damage status on the cutting edge of a competitors' insert used in this test and the AC8025P after turning the same number of works, the competitors' insert's cutting edge was largely missing and broken by the damage expanded from the point of the adhesion. On the other hand, the formation of adhesion and the progressive damage starting from the point of adhesion formation was suppressed in the AC8025P due to the surface smoothing treatment, achieving stable turning.

Figure 11 shows an application example of the AC8035P. When comparing heavy interrupted turning of the end faces of planetary pinion*3 (workpiece material: S35C)

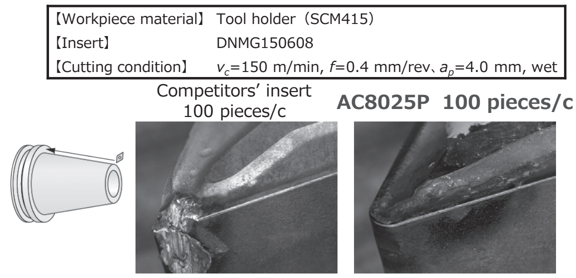


Fig. 10. Application example of AC8025P

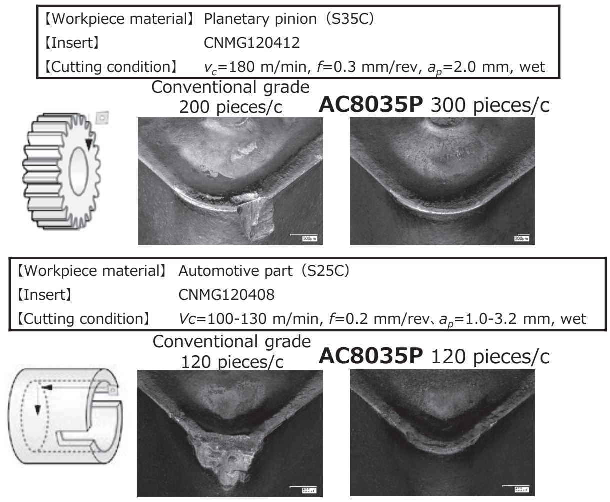


Fig. 11. Application example of AC8035P

by a conventional insert and by the AC8035P, the conventional grade showed a large fracture on the cutting edge after processing 200 pieces/c. On the other hand, due to its excellent fracture resistance, the AC8035P was able to continue turning even after processing 300 pieces/c without any fracture, 1.5 times more than the capability of the conventional insert. In the case of interrupted turning an automotive part (workpiece material: S25C) that involved cut-out portions, the AC8035P also achieved stable turning due to its excellent fracture resistance.

5. Conclusion

We have commenced sales of the following inserts: the AC8015P, which offers excellent crater-wear resistance in high-speed turning; the AC8025P, which realizes stable long tool life in general turning; and the AC8035P, which provides high stability by reducing the sudden fractures that can occur during interrupted turning due to a newly-developed coating and a special treatment on the surface of the coating. We expect to satisfy customers' various demands for productivity improvement and cost reduction in steel turning.

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 Field-emission scanning electron microscope (FE-SEM): A type of microscope that scans a specimen in a vacuum in a two-dimensional manner using electrons projected as a narrow beam. The intensity of the secondary electrons emitted from the surface of the specimen is then converted into an image.

∗3 Planetary pinion: A automotive part, often used in vehicle gearboxes.

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