Development of "ACE-COAT AC410K" Insert Grade for Cast Iron Turning

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Sumitomo Electric Hardmetal Corporation has developed the new coated carbide grade "AC410K" for cast iron turning application. The "AC410K" coated carbide adopts a newly developed chemical vapor deposition (CVD) coating "SUPER FF COAT" as its coating film. This new CVD coating consists of flat and smooth layers of fine-particle titanium carbonitride (TiCN) and aluminum oxide (alumina), and far surpasses conventional coatings in terms of resistance to wear and peeling and achieves the higher stability in machining operations. The new "AC410K" grade can satisfy demands of many customers for cost reduction and higher productivity of cast iron turning.

1. Introduction

Grades of indexable inserts for cutting operations are classified roughly as into grades such as cemented carbide, cermet, and cBN using independently, and coated grades that are with hard ceramic film surface coating. Particularly notable among the coated grades is coated carbide. It uses cemented carbide as a substrate and features both the strength of cemented carbide and the hardness of ceramic, while offering improved balance between wear and fracture resistance. The use of coated carbide has grown annually to now account for over 65% of the total shipped quantity of indexable insert grades [(1)].

In the industry fields where coated carbide inserts are used in machining operations, various efforts have been undertaken in recent years to lessen the impacts on the global environment and to use resources more efficiently. The same efforts are made also in machining of cast iron component parts used mainly in automobiles. A typical example of such efforts is reduction in weight of components for the purpose of reducing vehicle exhaust emissions and improving fuel efficiency. The reduction of weight involves each component having thinner wall thickness and more complex shape. In order to ensure adequate strength even with thin walls, work materials with high toughness are used. Therefore, machinability lowers significantly in terms of both shape and material choice. At the same time, there is also a strong user demand for increased speed and enhanced efficiency in machining operations to shorten lead time and reduce machining costs. In addition to these demanding requirements, users call for cutting tools that have longer tool life and exhibit more stable performance.

To satisfy these user needs, Sumitomo Electric Hardmetal Corporation has developed the "ACE-COAT AC410K" coated insert grade for cast iron turning applications. This new grade was made possible by optimizing the "Super FF Coat" [(2)] chemical vapor deposition (CVD) coating technology to best suit the usage for cast iron turning. The following describes the development background and characteristics of the new grade.

2. Required properties for cast iron turning tools

2-1 Cast iron machinability

Cast iron is a ferrous alloy containing a carbon content of 2.14% to 6.67%. It is classified roughly into two types depending on the morphology of graphite in the Fe matrix. One is gray cast iron (also called Ferrum Casting or FC) and the other is ductile cast iron (also called Ferrum Casting Ductile or FCD). **Figure 1** shows the typical microstructures and characteristics of gray cast iron and ductile cast iron. Gray cast iron is considered to be a relatively easy-to-cut material due to its characteristics. Graphite dispersed in the matrix serves as a lubricant, providing high thermal conductivity that allows frictional heat to be dissipated efficiently. Moreover, the internal notch effect of plate-like-shaped graphite flakes makes chips to be broken into small fragments before discharge. Ductile cast iron has strength and toughness higher than those of gray cast iron. Because its constituent graphite particles are of nodular

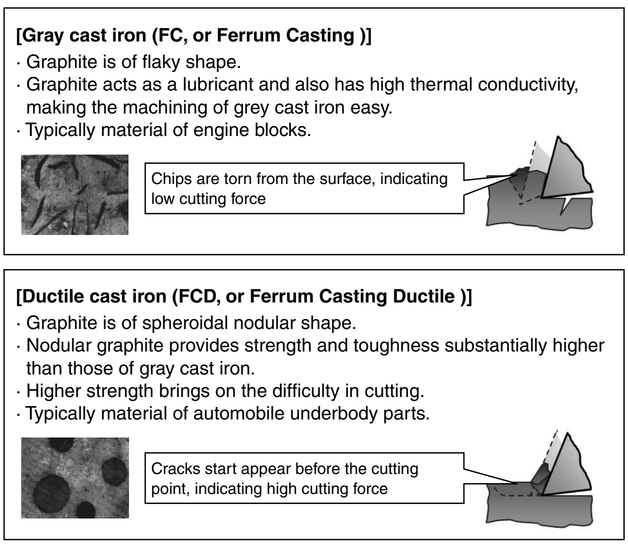


Fig. 1. Typical cast iron microstructures and characteristics

spheroidal shape, ductile cast iron is also called nodular graphite cast iron. Higher strength causes cracks to start prior to the cutting point; this increases the concentrated stress on the cutting edges as the cutting force becomes higher, resulting in reduced machinability. **Table 1** shows the typical machinability indices of gray cast iron and ductile cast iron.

Table 1. Machinability indices for cast iron

	Grade	Machinability index	
Gray cast iron	FC150	70	Easy-to-cut
	FC200	70	↑
	FC250	65	
	FC300	65	
	FC350	60	
Ductile cast iron	FCD450	55	
	FCD500	55	
	FCD550	50	↓
	FCD600	50	Hard-to-cut
	FCD700	45	

2-2 Required properties for cast iron turning tools

As shown in **Table 2**, the components of cast iron are stratified into hard constituents such as cementite or pearlite, and soft constituents such as graphite or ferrite. These hard constituents cause further abrasive wear against coating films and accelerate coating films abrasaion. While soft constituents adhere to cutting edge and deteriorate the roughness and texture of the surfaces of work materials. In addition, in the course of repeated adhesion and separation, part of tools may get torn and carried away by chips, resulting in abnormal damages such as peel off of coating films and chipping of cutting edges. Also, due to the method of manufacturing, cast iron may have gate remnants, burrs, or chilled surfaces. Such heterogeneity of work material surfaces causes unexpected fracture and other machining instabilities. Therefore, three properties are demanded of coated carbide grades for cast iron turning:

1) Resistance to abrasive wear caused by hard constituents in cast iron (High wear resistance)

2) Resistance to adherence of soft constituents or peel-off of coating films (High peeling resistance)

3) Machining stability uninfluenced by the surface conditions of work materials (High chipping resistance)

Table 2. Typical constituents of cast iron

Graphite	Soft constituent	
Silico-ferrite	↑	Adherence
Perlite		
Sorbite		
Steadite	↓	Abrasive wear
Oxidative products		
Cementite	Hard constituent	

3. Development objectives of AC410K

In addition to the property requirements of coated carbide grades for cast iron turning as described above, satisfying the market demands for improved speed and efficiency in machining was also set as a development target for AC410K. **Figure 2** shows a comparison of the application ranges of AC410K compared to AC300G, which is a conventional coated carbide grade of Sumitomo Electric Hardmetal. AC410K was developed with an objective of achieving good cutting capability and long tool life even in the higher cutting speed ranges, while also covering the AC300G application ranges from continuous to medium cutting of cast iron.

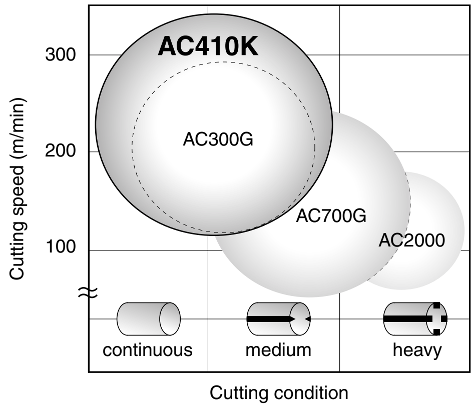


Fig. 2. Application range of AC410K

4. Features of AC410K

4-1 High wear resistance

Figure 3 shows a comparison of cross-sectional SEM images of the "Super FF Coat" coating film applied on AC410K and the conventional ceramic film on AC300G. The higher wear resistance of AC410K is achieved mainly by the refined grain size and higher hardness of TiCN film formed as the lower layer of ceramic film.

Table 3 shows a structural comparison of a conventional TiCN layer with a TiCN layer applied on AC410K.

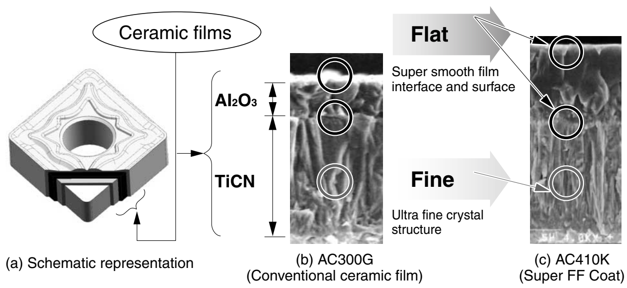
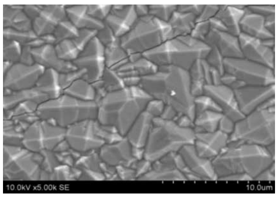
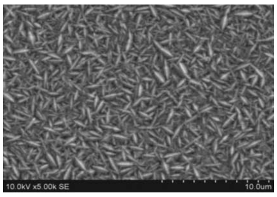
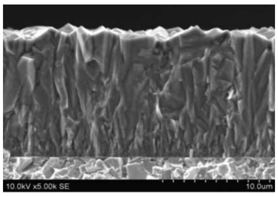
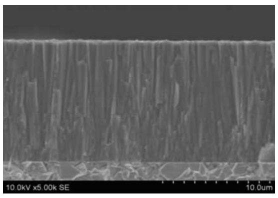


Fig. 3. (a) Schematic representation of CVD coated indexable insert
(b) Cross-sectional SEM image of conventional ceramic film
(c) Cross-sectional SEM image of Super FF Coat

With the Super FF Coating technology, compared to the conventional coating film, the Super FF Coat film has a significantly smaller grain size and a denser and more homogeneous structure. Because of these improved features of Super FF Coat, AC410K, as shown in **Fig. 4**, exhibits approximately 30% higher hardness, and experiences significantly less abrasive wear of coating film caused by abrasion against hard constituents.

Table 3. SEM images of surface and cross-sectional appearances of conventional ceramic film and Super FF Coat (TiCN layer)

	Conventional ceramic film	Super FF Coat
Surface structure		
Cross-sectional structure		

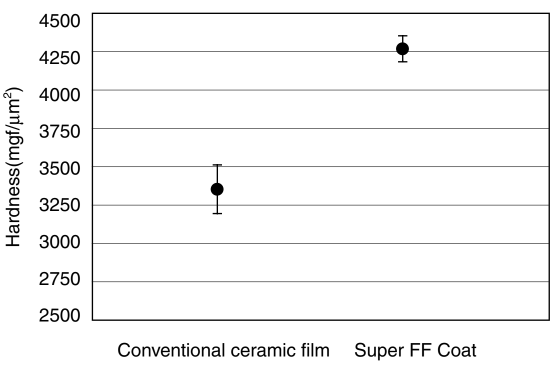


Fig. 4. Comparison of indentation hardness between conventional ceramic film and Super FF Coat (TiCN layer)

4-2 High peeling resistance

For easy identification of used corners, the outermost layer of a CVD coated carbide insert is coated with a Ti-based film for coloring purpose. However, because Ti-based film has a high affinity with work materials, work materials adhere to the cutting edges due to heat generated by machining. Therefore, in the case of AC410K, after ceramic film coating, the Ti-based film near each cutting edge is removed by a special machining process and the coating film surface is smoothed by polishing (**Table 4**). The smoothing of coating surfaces by machining exposes a chemically-stable alumina layer to the uppermost surface and at the same time significantly reduces the generation of heat by friction with work material, thus reducing the adhesion of coating film to cutting edge and improving the peeling resistance of the film.

It is relatively easy to smooth and polish the uppermost ceramic layer surface, but this is not easy on the inner ceramic layer of a multilayer coated carbide grades. A smooth inner layer film has an advantage that it prevents the work material from adhering to the cutting edge when the inner layer film is exposed due to the wear or peeling of the outer-layer film, resulting in further improvement of the adhesion to cutting edge and the peeling resistance of film.

The application of Super FF Coat to AC410K has achieved a smooth inner-layer film, which is impossible with machining. **Table 5** shows the measurement results for the surface irregularity and roughness of a TiCN film formed by the Super FF Coating technology for use on AC410K. As shown in the table, the inner-layer surface of AC410K is smoothed to have a roughness of about one-tenth of that of the coating film on the conventional grade. As indicated in **Fig. 5**, the resistance to adhesion and peeling of Super FF Coat is drastically improved compared with the conventional ceramic film.

Table 4. Comparison of surface condition before and after polishing

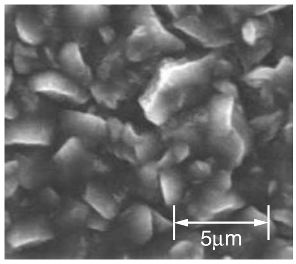
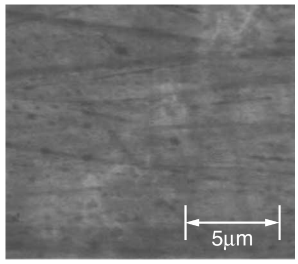
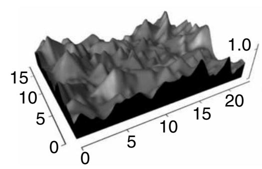
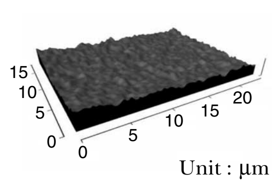
Before polishing	After polishing
	
Ra = 2.8 µm	Ra = 0.13 µm

Table 5. Topographic image and surface roughness of conventional ceramic film and Super FF Coat (TiCN layer)

	Conventional ceramic film	Super FF Coat
Topographic image of inner layer surface		 Unit : µm
Ra	0.1458 µm	0.0122 µm
Rz	0.6870 µm	0.0433 µm

4-3 High chipping resistance

The TiCN layer of Super FF Coat for AC410K is ultra-refined to one-tenth that of the conventional film. With this grain size ultra-refinement technique, the propagation of cracks formed due to unexpected impacts during machining can also be minimized. Moreover, Super FF Coat has an extremely high hardness while also having 50% less variations in hardness (standard deviation) than the conventional ceramic film (**Fig. 4**). Therefore, film fracture that is considered to be the cause of the variations in hardness can be decreased. AC410K achieves an outstanding chip resistance with its suppression effects on crack propagation and film damage.

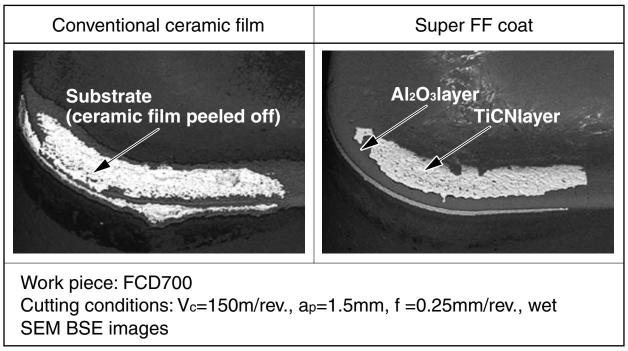


Fig. 5. Comparison of adhesion resistance and peeling resistance between conventional ceramic film and Super FF Coat

4-4 High heat resistance

For AC410K, a film of alpha-alumina having a thermally-stable crystal structure is applied for the outer layer. Alpha-alumina is of high hardness and high strength, and has a crystal structure that stays stable in high temperatures. As an alpha-alumina layer gets thicker, the size of alumina grains becomes coarse, resulting in the dramatic deterioration of film strength. Moreover, the increase in film thickness lowers the adhesion strength of the inner TiCN film layer. In the coating process of AC410K, the technique for forming an intermediate adhesion layer on the surface of the inner TiCN film layer was optimized. This makes the nucleation sites at which the alpha-alumina grains grow homogeneous, and also greatly improves the adhesion strength.

The Super FF Coating technology is applied also to alpha-alumina layer film coating. Such alpha-alumina film is twice as thick as the conventional ceramic film, while the grain size and adhesion strength of the two films are of the same level. With this super thick alpha-alumina layer film, AC410K shows a heat resistance extremely higher than that of conventional grades, enabling the operation of high-speed, high-efficiency machining that the market strongly demands.

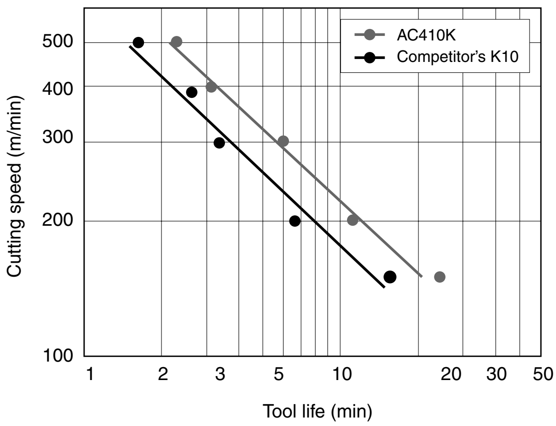
5. Cutting performance of AC410K

Figure 6 shows the cutting performance of AC410K. FCD 450 was cut at various speeds in a range of V_C = 150 m/min to 500 m/min. The cutting life was measured at each speed and the results were plotted on a double logarithmic chart. Note that the criterion for the tool life was set as a flank wear width (vb) of 0.25 mm. As is indicated in this chart, AC410K achieved 50% to 90% longer tool life than a competitor's product (K10 grade) in a cutting speed range of V_C = 150 m/min and faster. In addition, as shown on the chart by a solid line, in the case of AC410K, cutting speed is clearly correlated with tool life. This suggests that AC410K has less anomalous damage caused by chipping and film peeling.

Figures 7, **8, and 9** show the comparisons of actual user use of AC410K and the conventional grade.

Figure 7 shows the actual user use on gray cast iron FC250. Super FF Coat's high resistance to abrasive wear reduces flank wear by 50% or more even when the machined quantity is 2.5 times that of existing grade.

Figures 8 and 9 show the actual use on ductile cast iron, which is considered as a hard-to-cut material. With AC410K, tool damage (flank wear) is greatly reduced by 25% or more for the machining of ductile cast iron, even when machined quantity is 1.5 times that the case with the existing grades. AC410K also has achieved a drastically longer life compared to the conventional grades, whether used on gray cast iron (FC) or ductile cast iron (FCD).



Work piece: FCD450 Holder: PCLNR2525-43 Insert: CNMG120408
Conditions: a_p=1.5mm, f =0.25mm/rev, wet
Criteria: v_b=0.25mm

Fig. 6. Cutting performance of AC410K

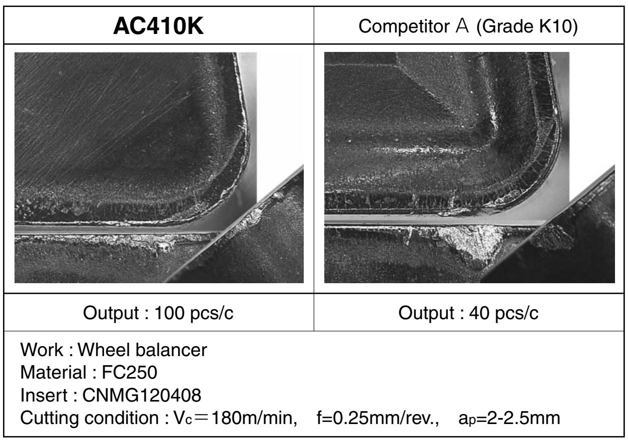


Fig. 7. Example of cutting using AC410K (1)

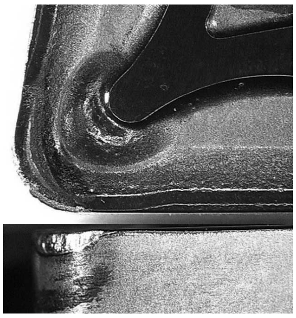
AC410K	Conventional grade
	
Output: 200 pcs/c	Output: 130 pcs/c
Work: Steering knuckle Material: FCD450 Insert: WNMG080412N-UX Conditions: V_c=170-230m/min, f=0.2mm/rev., a_p=1.5mm	

Fig. 8. Example of cutting using AC410K (2)

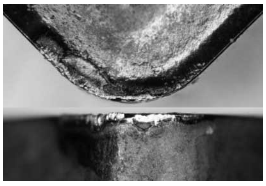
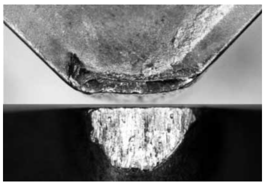
	AC410K	Competitor B (K10 grade)
		
Output	800pcs/c	550pcs/c
Work: Steering knuckle Material: FCD450 Insert: SNMG120412 Conditions: V_c=270m/min, f=0.2mm/rev.		

Fig. 9. Example of cutting using AC410K (3)

6. Conclusions

ACE-COAT AC410K is a new insert grade that offers long tool life and improves stability, speed, and efficiency during machining to satisfy user requirements for cast iron turning. This new grade is expected to contribute greatly in reducing machining costs at user side.

References

(1) JCTMA No.370 2007-6

(2) Yoshio Okada "Development of New CVD-Coating 'Super FF Coat' and Its Application to Cutting Tools" SEI Technical Review, No.64 April 2007

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