Development of "ACE-COAT AC420K" Coated Carbide and "SUMIBORON BNC500" Coated PcBN for Cast Iron Turning

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Among the many kinds of workpiece materials, cast iron is used for making a variety of products ranging from household appliances to industrial products and machine parts. Reflecting the recent growth in global environmental conservation awareness, parts manufacturers have been switching parts material from conventional gray cast iron to spheroidal graphite cast iron (ductile cast iron), in order to reduce the wall thickness and weight of their products. Ductile cast iron is higher in tensile strength, but more difficult to cut, than gray cast iron. Accordingly, market needs have been increasing for cutting tools that can be used in increasingly severe conditions while maintaining long tool life and high reliability.

To meet such needs, we have developed the coated carbide insert "Ace Coat AC420K" and a coated PcBN insert "Coated Sumiboron BNC500." The former is suitable for rough cutting of ductile cast iron, while the latter is suitable for finish cutting of ductile cast iron.

This paper describes the development background and performance of these inserts.

Keywords: cast iron turning, CVD, PcBN, ductile cast iron

1. Introduction

Indexable inserts for cutting tool applications ("inserts") are made of cemented carbide, cermet, ceramics, cBN sintered body (PcBN), and diamond sintered body. Coated carbide, coated cermet, coated ceramics and coated PcBN are made by coating the first four materials with a hard ceramic film. **Figure 1** shows cutting tool materials and their positioning. Among these materials, coated carbide offers well-balanced wear resistance and chipping resistance; inserts made of this material are widely used for various metal-cutting applications. In Japan, the production volume of coated carbide inserts accounts for approximately 70% of total inserts.

Cermet, coated cermet, PcBN and coated PcBN inserts, extremely hard and heat resistant, are used for finishing. In particular, coated PcBN inserts, comprising a cBN sintered body coated with a hard ceramic film, achieve significantly higher cutting accuracy, with longer tool life, than conventional PcBN inserts. However, not all of these inserts can efficiently cut all workpiece materials; different inserts are chosen for different applications.

Among the many kinds of workpiece materials, cast iron is used for making a variety of products ranging from household appliances to industrial products and machine parts. Reflecting the recent growth in global environmental conservation awareness, parts manufacturers have been switching parts material from conventional gray cast iron to spheroidal graphite cast iron (ductile cast iron), in order to reduce the wall thickness and weight of their products. Ductile cast iron is higher in tensile strength, but more difficult to cut, than gray cast iron. In addition, cutting tool uses are becoming increasingly severe, such as interrupted cutting of intricately shaped parts, rough cutting of as-cast parts, and high-speed/high-accuracy finishing. Also, market needs have been increasing for cutting tools with longer tool life and greater reliability.

To meet such needs, we have developed the coated carbide insert "Ace Coat AC420K" and a coated PcBN insert "Coated Sumiboron BNC500." The former is suitable for rough cutting of ductile cast iron, while the latter is suitable for finish cutting of ductile cast iron.

This paper describes the development background and performance of these inserts.

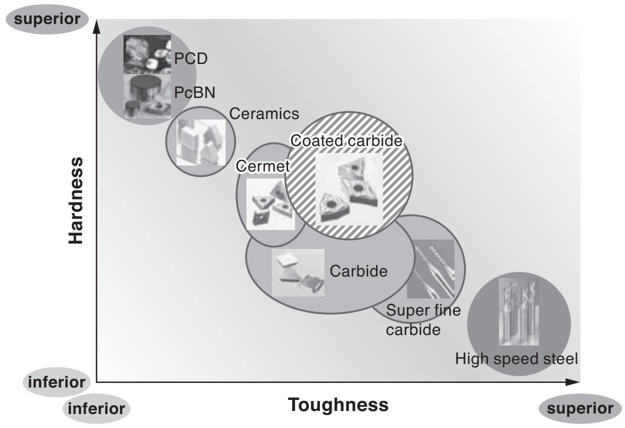


Fig. 1. Hardness and toughness of tool materials

2. Cutting Tool Market Trends and Cast Iron Machinability

Owing to their excellent formability and machinability, cast metals have been used to make a variety of industrial products since the Industrial Revolution began in England in the 18th century. Typical examples of automotive machine parts made of cast iron include engine cylinder blocks, crankshafts, camshafts, exhaust manifolds, oil pump housings and brake rotors. These parts are complex in shape and must be highly wear resistant, vibration resistant, heat resistant, and heat conductive. Molten metal is poured into a sand or metal mold to form a complex part of desired configuration. Cast iron, a composite material of iron and graphite, is characterized by hardness and toughness required for most machine parts. Graphite suppresses vibration, lubricates, reduces wear and resists heat and corrosion. The change in total casting production volume in the world's major countries is shown in **Fig. 2**[1]. These countries increased production steadily until 2007, the year before Lehman's fall, though the rate of increase differs depending on the country.

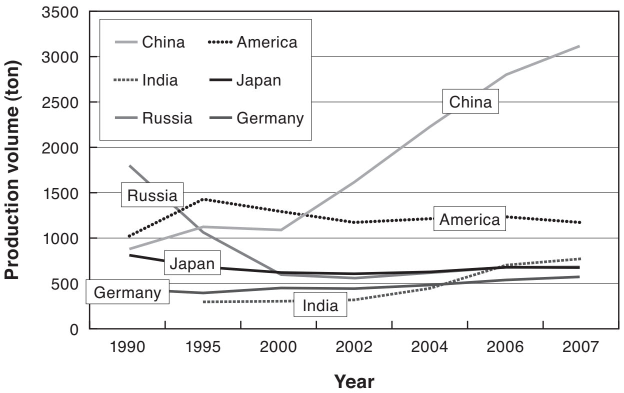


Fig. 2. Trend of production volume of world's main country[1]

It is generally recognized that the brittleness of graphite in cast iron lowers tensile strength but improves machinability, as compared to steel. However, cast iron will degrade machinability if the casting technique is so poor that it chills the casting surface, leaves molten metal at the pouring gate, produces casting fins or causes sand inclusion. Cast iron part manufacturers are actively switching their material from low-strength, highly machinable gray cast iron to high-strength, difficult-to-cut ductile cast iron or alloy cast iron, so as to increase productivity by reducing product weight or wall thickness, or by replacing conventional molds with multiple casting molds. Since the state of graphite differs between gray cast iron and ductile cast iron, chip configurations differ as shown in **Fig. 3**. Since the metallographic structure of gray cast iron consists of flaky graphite, this material is cut while being broken microscopically by cutting edges. In contrast, ductile cast iron containing spheroidal graphite produces relatively long chips since its metallographic structure is difficult to break and its tensile strength is high. Ductile cast iron of a particular metallographic structure adheres heavily to the cutting edges. At the same time, hard microparticles of ductile cast iron, which are characteristic of ductile cast-iron products, abrade cutting edges excessively and accelerate degrading of their sharpness.

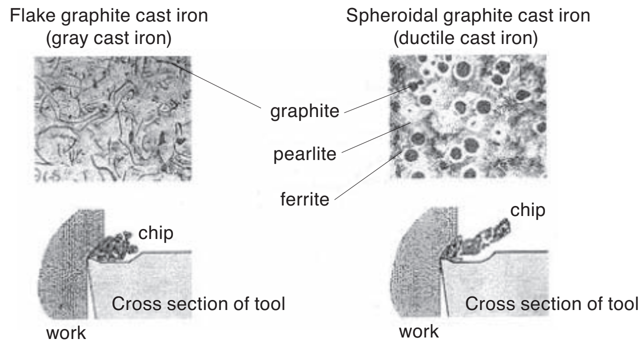
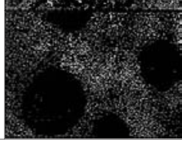


Fig. 3. Micro structure of cast iron and chip generation

Figure 4 shows some examples of the relation between insert damage and workpiece material. When gray cast iron is cut, insert flanks are damaged more heavily than rake faces. In the case of cutting steel, chips are discharged continuously and the rake faces are damaged more seriously than insert flanks. Ductile cast iron exhibits both of the above damage patterns, clarifying that it is more difficult to cut. **Table 1** shows the features and machinability ratio of major cast irons.

Table 1. Micro structure and machinability of typical cast iron

	grade	Machinability index		Micro structure	Remarks column
Gray cast iron	FC150	70	Easy-to-cut		Easy-to-cut because flake graphite makes chips to pieces
	FC200	70			
	FC250	65			
	FC300	65			
	FC350	60			
Ductile cast iron	**FCD450**	55			Hard-to-cut because of spheroidal graphite
	FCD500	55			
	FCD550	50			
	FCD600	50			
	FCD700	45	Hard-to-cut		
Vermicular graphite cast iron	FCV350	60	Material intermediate between FC250 and FCD450. Easy to adhesion		
Blackheart malleable cast iron	FCMB35	110	Easy-to-cut		
Austenitic cast iron	FCA	50	Including Ni and Cr make machinability worse		

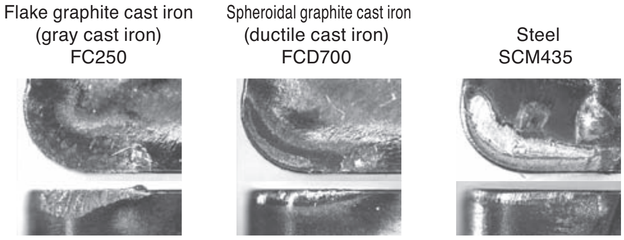


Fig. 4. Damage mode of the cutting edge

3. Coated Carbide and Coated PcBN Inserts: Required Characteristics and Features

3-1 Characteristics required of coated carbide insert AC420K

As-cast rough surfaces of high-strength, difficult-to-cut ductile cast iron often suffer such defects as fins, sand inclusion and chilled surface structures. When as-cast surface is removed by rough cutting, the cutting edges suffer adhesion and micro-chipping, as shown in **Fig. 5**; this often leads to sudden breakage. When an intricately shaped cast iron workpiece, which is characteristic of a casting, is additionally cut interruptedly, chipping of the cutting edges will further be promoted. As a result, insert tool life becomes unstable, making insert control difficult. There is growing market need for inserts with higher reliability and longer tool life that can remove as-cast surface and cut interruptedly and roughly ductile cast iron workpieces.

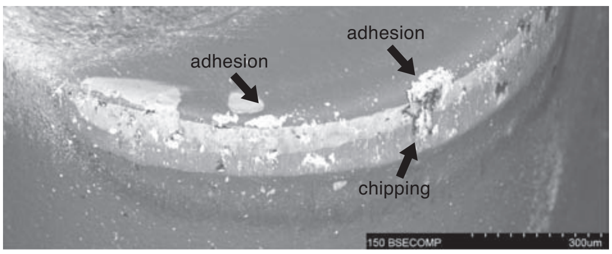


Fig. 5. Initial damage of the cutting edge for FCD cutting by coated carbide

3-2 Features of coated carbide insert AC420K

The lineup of our coated carbide inserts used for cast iron cutting is shown in **Fig. 6**[2]. AC410K is used to cut cast iron continuously and interruptedly, with high abrasive wear resistance. The newly developed AC420K is used to cut cast iron interruptedly and roughly, with high adhesion, peeling and chipping. Thus the AC410K and AC420K cover the entire range of tasks in which coated carbide inserts must be used.

AC420K consists of a special purpose cemented carbide substrate and a special purpose CVD coating film, called "Super FF Coat," shown in **Fig. 7**.

Particularly high chipping resistance is required of inserts when used to remove as-cast surface through interrupted cutting. To meet this requirement, inserts for this application must be coated with a film of increased strength. **Figure 8** shows the photographed metallographic structures of a carbonitrided titanium (TiCN) film formed by a traditional technique and an FF-TiCN film formed by the Super FF-Coating technique. This figure confirms that the FF-Coating technique significantly minimizes film-particle size and distributes the fine particles densely and evenly throughout the film structure. Thus this technique gives TiCN films higher strength and chipping resistance.

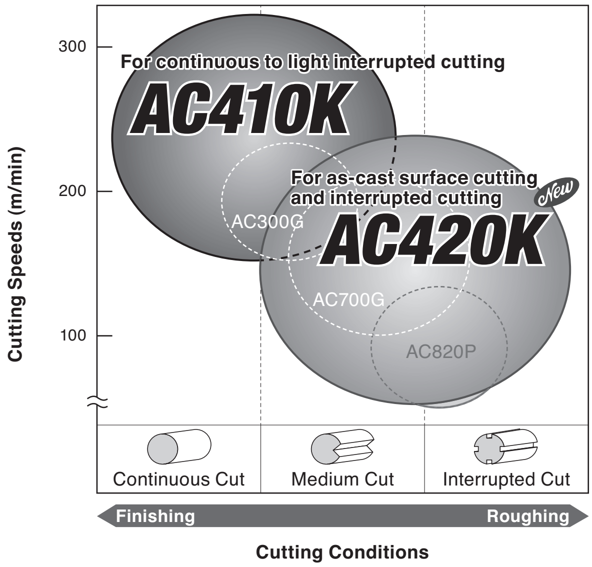


Fig. 6. Grade map for cast iron turning

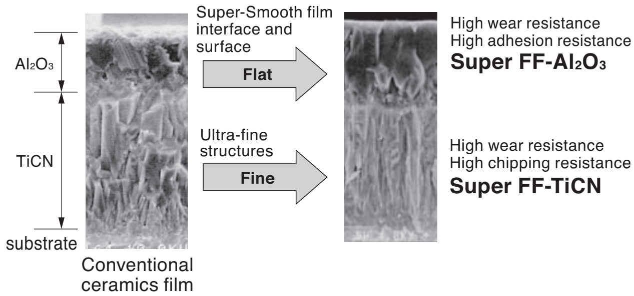


Fig. 7. Cross section of AC420K coating

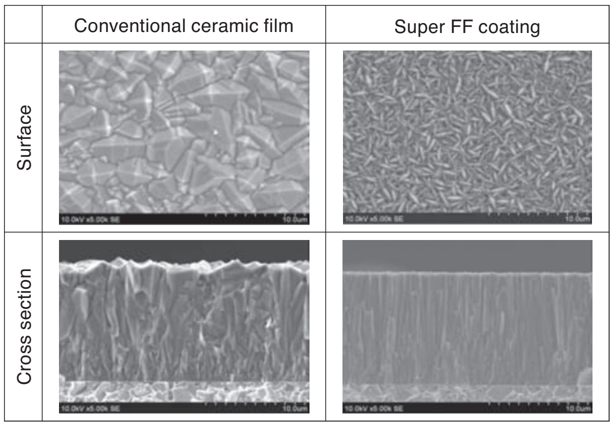


Fig. 8. Feature of super FF coating "FF-TiCN"

In addition, alpha alumina oxide, having high-temperature stability and hardness, is used as the FF coating film material. Conventional films made from alpha alumina often degrade surface smoothness because of wider particle size distribution, enabling adhesion on the cutting edges, accelerating their damage by chipping. Surface roughness of alpha alumina film can be halved by optimizing the film forming conditions, as shown in **Fig. 9**.

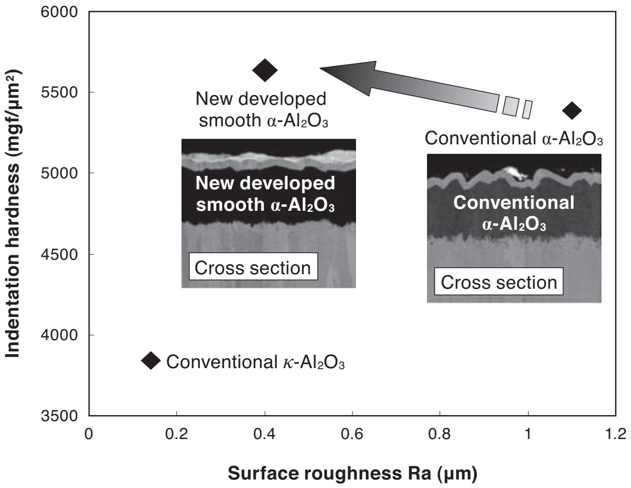


Fig. 9. Feature of super FF coating "FF-α Al_2O_3"

In addition to the Super FF-Coat technique, we have established a coating film internal stress control technique. With this technique, we succeeded in transforming some of the residual tensile stress, which is characteristic of CVD coating films, to compressive residual stress. As a result, the new inserts improved dramatically in terms of resistance to adhesion and chipping at the cutting edge.

As shown in **Photo 1**, the AC420K inserts have a black surface resulting from special surface treatment, whose objective is to create a high oxidation-resistant and adhesion-resistant alpha Al_2O_3 film in the outermost layer of the coating film, thereby protecting the inserts from chipping failure due to adhesion.

Figure 10 shows the chipping resistance evaluation test results for the AC420K inserts and competing inserts. In this test, the inserts were subjected to heavy interrupted cutting of high-strength, low-machinability ductile cast iron FCD having an as-cast groove. The cutting edge of the competitor's inserts chipped at 150 seconds after test commencement, while the AC420K inserts cut the workpieces stably, without significant adhesion or edge chipping, for approximately twice as long.

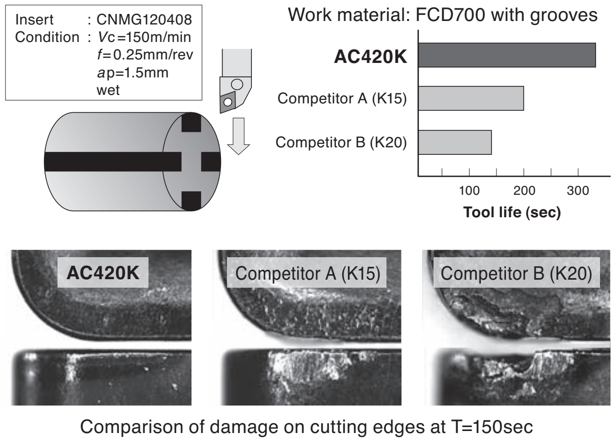


Fig. 10. Cutting test result of interrupted cutting and as-casted work cutting

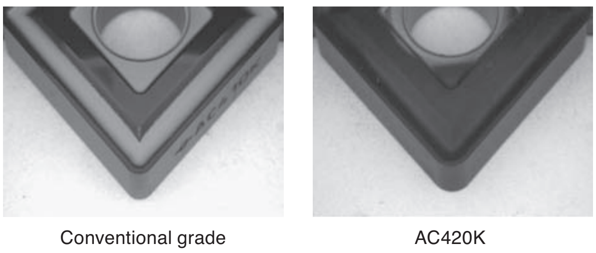


Photo 1. Appearance of special surface treatment of AC420K

3-3 Characteristics required of coated PcBN, BNC500

Castings are first cut roughly with AC420K inserts to remove as-cast surface, then finished accurately with coated PcBN inserts called BNC500. Even the most advanced coated carbide inserts cannot achieve a practical tool life when used to cut difficult-to-cut ductile cast iron at a high speed of 300 m/min or more. Our PcBN inserts are often used for such applications.

Figure 11 shows the factor analysis results, obtained at a customer's site, for the tool life of PcBN inserts. This figure confirmed that 70% or more of the total number of unacceptable workpieces was due to defective surface-finish accuracy attributable to insufficient wear resistance of inserts. On the basis of these results, we set the target wear resistance of the BNC500 inserts at twice that of conventional PcBN inserts.

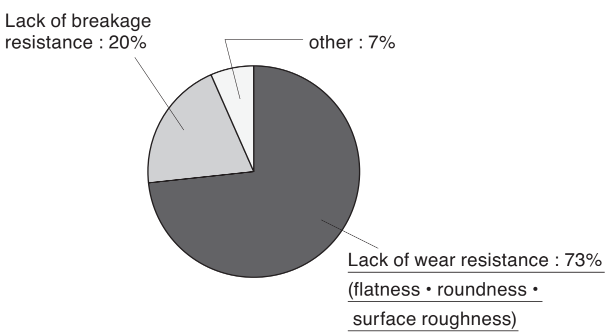


Fig. 11. Criteria of PcBN tool life in ductile cast iron cutting

3-4 Features of coated PcBN inserts BNC500

Major features of the BNC 500 inserts are shown in **Fig. 12**. For the inserts to be used in cutting ductile cast iron, TiC is usually employed as a PcBN binder, to increase wear resistance. In developing the BNC500 inserts, we drastically modified the traditional TiC binder production process and succeeded in purifying TiC by reducing its impurity content to one-tenth or less of the previous level. As a result, the wear resistance of the BNC500 inserts increased to 1.5 times that of conventional cBN inserts, without diminishing chipping resistance. We also coated the BNC500 inserts with special-purpose high heat-resistant TiAIN, to finally increase the insert wear resistance to twice that of conventional PcBN inserts. The TiAIN coating was originally employed for the Sumiboron BNC series[3] inserts, which are used to cut hardened steel.

Material	cBN sintered body					Coating
	cBN content [vol%]	cBN particle size (μm)	Binder material	Hardness [GPa]	TRS [GPa]	
BNC500	60-65	4	High-purity TiC	32-34	1.0-1.1	TiAIN
BN500	65-70	6	TiC	32-34	1.0-1.1	Non coated
Ceramics				20-25	0.7-0.9	–
Coated carbide				15-20	2.0-3.0	–

Fig. 12. Features of BNC500

FCD450 bars were bored with a BNC500 tool and a conventional PcBN tool.

Dimensional variation of the bores and a photograph of each tool's cutting edge are shown in **Fig. 13**. The conventional PcBN tool frequently required correction of its cutting edge positions, since the edges were worn quickly on the flank, changing the bore diameter and exceeding the specified tolerance of 30 μm. In contrast, the highly wear-resistant BNC500 tool maintained bore diameter variation within a small range, confirming that this tool can bore a workpiece 10 times or more longer than conventional PcBN tools until the first edge positional correction is needed.

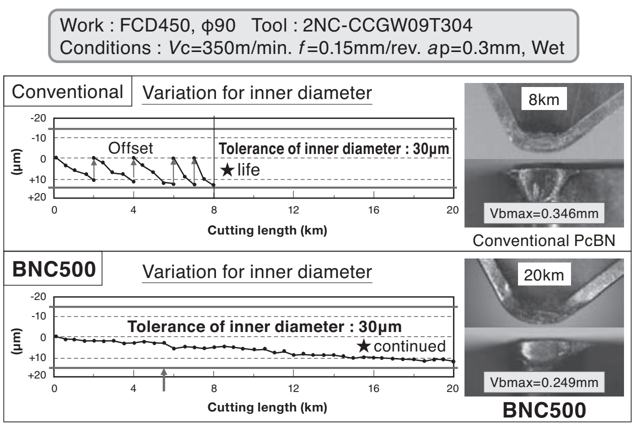


Fig. 13. Wear resistance and dimension accuracy of BNC500

Figure 14 compares outside surface roughness of FCD700 bars finished by a BNC500 tool and a ceramic tool. The ceramic tool generated intensive microscopic chipping along the cutting edge lines when the cutting length reached 3 km, thereby losing edge sharpness and increasing cut surface roughness. In contrast, the BNC500 tool maintained sharp cutting edges and cut the material with a high surface accuracy. **Figure 15** shows the Vc-T diagram of FCD700 bars drawn with two surface roughness levels (Rz = 12.5 μm and 1.6 μm) taken as the tool life criteria. For a surface roughness of Rz = 12.5 μm, both cemented carbide and ceramic tools can be used, but their tool life decreases sharply when Vc exceeds 300 m/min. In contrast, the BNC500 tools maintain their practical tool life even under the above conditions. For a surface roughness of Rz = 1.6 μm, neither cemented carbide nor ceramic tools can reduce the surface roughness to this level from the beginning, but BNC500 tools can practically smooth the surfaces to this level.

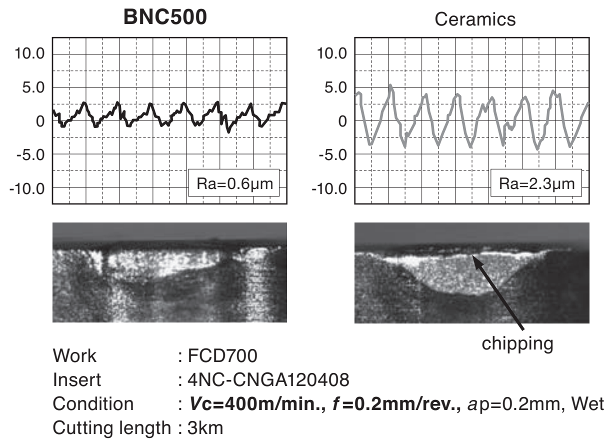


Fig. 14. Surface roughness comparison between BNC500 and ceramics tool

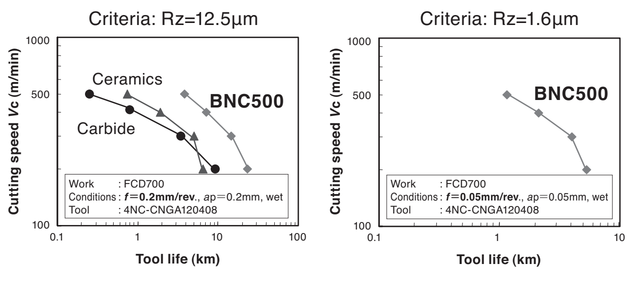


Fig. 15. Vc-T diagram (Criteria: surface roughness)

4. Application Range of Cutting Tools for Ductile Cast Iron: Actual Use Examples

Figure 16 shows the application range of various types of cutting tools for ductile cast iron cutting. Coated carbide tools are recommended for rough cutting to a depth of more than 0.5 mm. In such a particularly unstable process as as-cast surface removal by interrupted cutting, AC420K tools exhibit excellent reliability and long tool life. BNC500 tools are recommended for high-accuracy finish cutting with a low surface roughness of 6.3 z or less, and a dimensional accuracy of IT Class 6. These tools can be used for 300 m/min or higher-speed cutting applications.

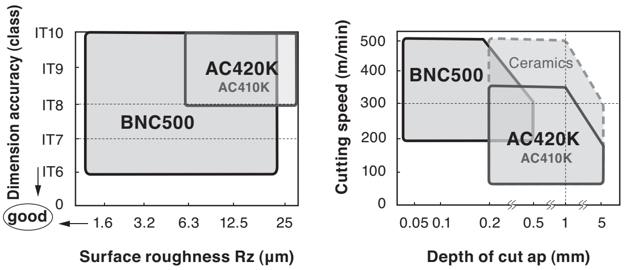


Fig. 16. Recommendation area of tool materials for ductile cast iron cutting

Figure 17 shows practical examples of AC420K and BNC500 tool uses. The AC420K tool demonstrated excellent chipping resistance, high reliability and long tool life in rough cutting of ductile cast iron. On the other hand, the BNC500 tool demonstrated remarkably high wear resistance in finish cutting of ductile cast iron, with a specified high dimensional accuracy and long tool life, twice that of conventional tools.

5. Conclusion

Coated carbide inserts Ace Coat AC420K and coated PcBN inserts "Coated Sumiboron BNC500," respectively used mainly for rough cutting and finish cutting of ductile cast iron, meet a multiplicity of market needs for rough, interrupted, high-speed and high-accuracy cutting of ductile cast iron at high efficiency and with long tool life. They are expected to significantly reduce cutting cost, improve productivity and enhance cutting accuracy in fabricating more difficult-to-cut cast iron parts.

* Ace Coat, Sumiboron and Super FF Coat are trademarks or registered trademarks of Sumitomo Electric Industries, Ltd.

Technical Term

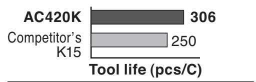
*1 CBN (cubic boron nitride): Has hardness and thermal conductivity next to diamond, and has low reactivity with ferrous metals.

*2 CVD (chemical vapor deposition): One of the coating methods using chemical reaction.

*3 Machinability index : Numerical number of machinability degree from tool life.

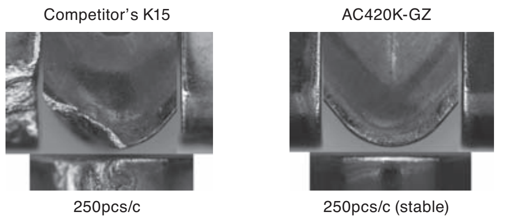
● Rough cutting of ductile cast iron

Work material : diff case (FCD450)
Tooling : outer diameter roughing



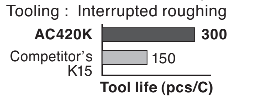
AC420K achieved 1.2 times longer tool life than competitor's

Grade	AC420K
Insert	CNMG120412
Vc m/min	180
f mm/rev	0.2
ap mm	1.5-2.0
Coolant	Wet



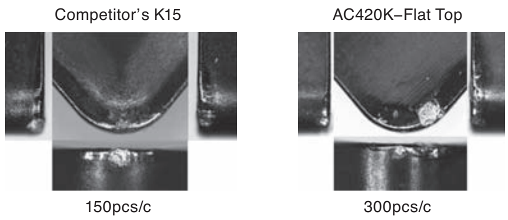
● Interrupted cutting of ductile cast iron

Work material : CAM SHAFT (FCD700)
Tooling : Interrupted roughing



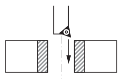
AC420K achieved 2 times longer tool life than competitor's

Grade	AC420K
insert	WNMG080408
Vc m/min	90-254
f mm/rev	0.15-0.3
ap mm	1mm –
Coolant	Wet



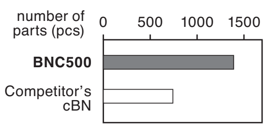
● I.D. boring of FCD part

Work : knuckle part (FCD450)
process : boring



Criteria : Rz12.5, φ95±0.015(IT7)

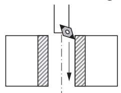
Grade	BNC500
Insert	3NC-TPGW110308
Vc m/min	400
f mm/rev	0.2
ap mm	0.2
Coolant	Wet



- Competitor's cBN had large flank wear
- **BNC500 achieved two times longer tool life than competitor's cBN by excellent wear resistance.**

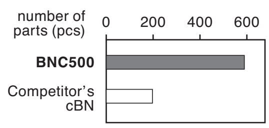
● I.D. boring of FCD part

Work : AT case sleeve (FCD450)
process : I.D. boring



Criteria : Rz12.5, φ85 ± 0.015(IT7)

Grade	BNC500
Insert	2NC-CCGW09T304
Vc m/min	350
f mm/rev	0.15
ap mm	0.3
Coolant	Wet



- Competitor's cBN had large flank wear
- **BNC500 achieved three times longer tool life than competitor's cBN by excellent wear resistance.**

Fig. 17. Application examples

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