Development of New Coated Carbide Grade AC6030M/AC6040M for Stainless Steel Turning

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In recent years, a demand has increased for stainless steel having good recyclability and low environment load. However, due to its property of being difficult to attain stable processing with high efficiency, stainless steel is classified as one of the "difficult-to-cut materials". In order to resolve problems of stainless steel turning, Sumitomo Electric Hardmetal Corporation has developed new coated carbide grades "AC6030M" applied with new CVD coating technology "Absotech Platinum" and "AC6040M" applied with new PVD coating technology "Absotech Bronze," along with new chip breaker "EM-type." Having high wear- and chipping-resistance, AC6030M is a material for general processing. Having excellent fracture resistance, AC6040M is a material for intermittent machining. These new materials and new chip breaker can satisfy customer demands for cost reduction and higher productivity of stainless steel turning.

Keywords: turning, coated carbide, CVD, PVD, stainless steel

1. Introduction

Indexable insert grades made of a cemented carbide substrate provided with a hard ceramic coating (hereinafter referred to as "coated grades") used in cutting tools are superior, considering a balance between wear resistance and fracture resistance, to other cutting tool grades. Consequently, their use has been increasing each year, currently accounting for 70% of all indexable insert grades (**Fig. 1**).

Various iron and steel workpieces including carbon alloy, stainless steels and cast iron are cut with coated grades. Among materials, demand for stainless steel is growing every year due to request for global environmental conservation and resource saving these days, since corrosion-resistant stainless steel requires no solvent coating, is low in impact on the environment, is highly recyclable, and, consequently, is eco-friendly (**Fig. 2**).

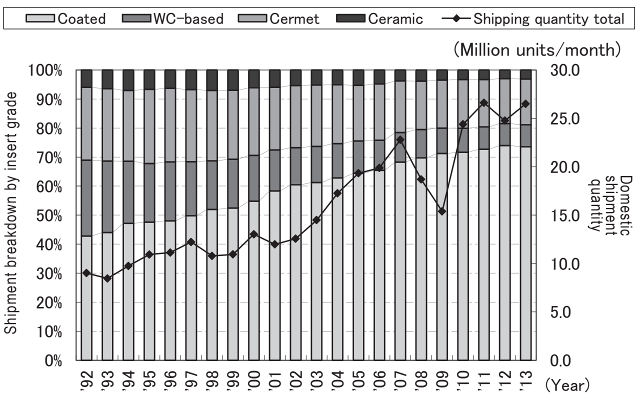


Fig. 1. Indexable insert shipment breakdown by grade and domestic shipping quantity[(1)]

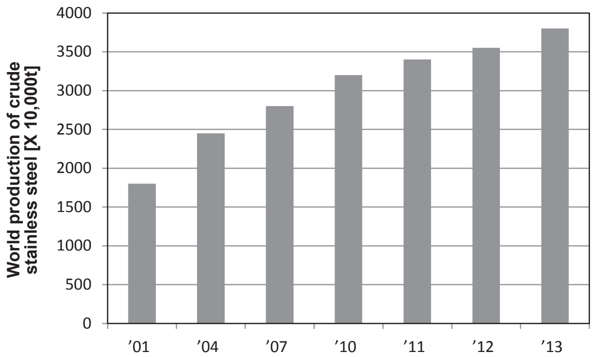


Fig. 2. World production of crude stainless steel[(2)]

However, stainless steel cutting problems include: (1) Cutting edges often chip due to the tendency of work surfaces to harden; (2) Cutting edges tend to undergo plastic deformation from high temperatures due to the tendency of stainless steel to retain cutting heat due to its relatively low thermal conductivity; and (3) Workpieces tend to produce a built-up edge due to the high affinity of stainless steel to cutting tool grades. Stainless steel has been a difficult-to-cut material due to these properties. Consequently, the challenge has been the difficulty in achieving high-efficiency and stable cutting of stainless steel.

As solutions to these problems, Sumitomo Electric Hardmetal Corporation has developed the Chemical Vapor Deposition*[1] (CVD) turning grade AC6030M with the new CVD coating Absotech Platinum, the Physical Vapor Deposition*[2] (PVD) turning grade AC6040M with the new PVD coating Absotech Bronze, and the chip breaker for rough machining EM-Type. The following sections describe the development process and the performance of these products.

Table 1. Stainless steel grades and their features

	Typical stainless steel grades	Major components	Key features	Example uses
Austenite	SUS304	18%Cr-8%Ni	High-temperature strength, low-temperature toughness, workpiece hardness, and non-magnetic	Industrial facilities, medical equipment, and vehicles
	SUS 316	18%Cr-12%Ni-2%Mo		
Ferrite	SUS430	18%Cr, Low carbon	Corrosion resistance and machinability	Domestic water heaters and mufflers
	SUS444	19%Cr-2%Mo-Ti,Nb,Zr		
Martensite	SUS410	13%Cr	Hardening by quenching	Cutting tools and turbine blades
	SUS440	18%Cr		
Two-phase (austenite ferrite)	SUS329J1	25%Cr-4.5%Ni-2%Mo	Resistance to seawater and high hardness	Chemical plants and ships
	SUS329J4L	25%Cr-6%Ni-3%Mo, Low carbon		
Precipitation hardening	SUS630	17%Cr-4%Ni-4%Cu-Nb	Strength enhanced by heat treatment	Aircraft, spacecraft, and yachts
	SUS630	17%Cr-7%Ni-Al		

2. Types of Stainless Steel and Market Trends

2-1 Types of stainless steel

Stainless steel is a steel alloy with a minimum of 10.5% chromium content. It is extremely resistant to corrosion in comparison with general steels. Stainless steels are classified into five types according to the contents of chromium, nickel, and other metal elements, as well as according to metal structure (**Table 1**).

Among stainless steel grades, austenitic stainless steel is most important, accounting for approximately 60% of all stainless steel materials. In addition to being corrosion resistant, austenitic stainless steel is highly durable, heat resistant, and strong, and therefore is used in all areas including, building materials, automotive parts, chemical plants, food plants, nuclear power plants, chemical plants general industrial equipment, and water pipes.

2-2 Trends in our users working on stainless steel processing

Recently, our users working on stainless steel processing in different regions tend to use different workpieces, cutting conditions, and tools.

Our users in Japan, Europe and America tend to work increasingly on difficult-to-cut materials including two-phase and precipitation hardening stainless steels, although the percentage of austenitic stainless steel use is still high. They use a high percentage of highly wear-resistant and versatile CVD grades, since they often turn large workpieces such as marines shafts and pumps.

In contrast, our users working on stainless steel processing in emerging economies, including China, mostly process austenitic stainless steel in a small-rot multi-production style (producing valves and nuts). They use low-rigidity equipment and place importance on processing efficiency, working largely on workpieces of high variability (in structure, hardness, surface roughness, etc.), which results in unstable machining, or workpieces involving intermittent machining, which cause inserts to fracture frequently. For these reasons, they tend to use a high percentage of highly fracture-resistant PVD grades.

These market features and trends were taken into consideration when determining the course of development and performance targets for the new stainless steel turning grades AC6030M and AC6040M with the new EM-Type chip breaker.

3. Development of AC6030M/AC6040M

Figure 3 shows Sumitomo Electric Hardmetal Corporation's lineup of stainless steel turning coated grades. Three grades the AC610M, AC6030M and AC6040M cover all areas from high-speed and continuous machining to low-speed and intermittent machining of stainless steel. The AC610M is a highly wear-resistant CVD grade for high-speed and continuous machining, while the AC6030M is between the other two grades, covering a wide area from medium-speed continuous machining to intermittent machining.

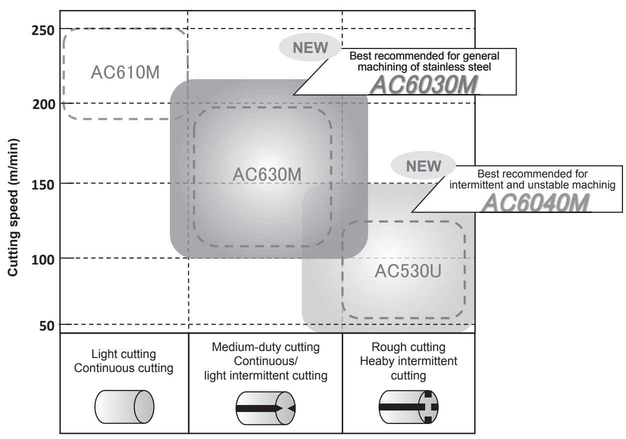


Fig. 3. Applicable ranges of AC6030M/AC6040M

The AC6040M is a very strong and impact-resistant PVD grade.

3-1 AC6030M development goals

To set clear development goals for the AC6030M, we analyzed used CVD grade AC630M[3] inserts collected from users. The analysis results revealed that AC630M was highly wear-resistant, yet it had poorly consistent (reliable) tool life due to cutting edge chipping.

According to the analysis results, one important challenge for the AC6030M to meet was to reduce chipping and edge fracture during intermittent cutting. The performance targets were set at 1.5 times higher fracture resistance than that of predecessor grades and a higher level of wear resistance than all of our competitors' marketed grades.

3-2 Development of AC6030M

The newly developed coating Absotech Platinum is applied to the AC6030M. This technology comprises a newly developed boride-titanium compound coating and Sumitomo Electric Hardmetal's proprietary CVD coating Super FF Coat.

(1) Improved chipping resistance

An analysis of the damage mechanism working in the chipping of the predecessor AC630M revealed that chipping started in the alumina coating on the cutting edge.

A cause of chipping of CVD coatings is residual tensile stress in the coating. Residual stresses are generated due to differences in the thermal expansion coefficients of the coating and cemented carbide substrate. Cracks develop more in the coating under a cutting load with increasing residual tensile stress, and cause chipping and/or peeling of the coating. Conversely, a coating that has a residual compression stress retards crack development and is therefore a highly chipping-resistant coating.

The AC6030M successfully reduces residual tensile stresses generated in alumina coating by using a newly developed boridebased-titanium compound coating as the outer layer (**Table 2**). The reduction in residual tensile stress, or a cause of chipping, has led to substantially improved tool stability (reliability).

Table 2. Residual tensile stresses in conventional coating and AC6030M coating

	Residual stress in coating
Coventional coating	800 MPa
AC6030M (Absotech Platinum)	200MPa

(2) Improved adhesion resistance

The AC6030M is subjected to surface smoothing after coating to improve in resistance to adhesion. Surface smoothing provides better surface roughness of the coating (**Fig. 4**) and significantly reduces frictional resistance between tool and workpiece. The exposure of an alumina coating improves the adhesion

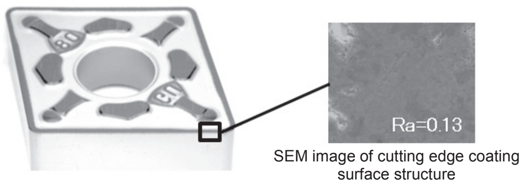


Fig. 4. Appearance of AC6030M and cutting edge surface roughness

resistance and chip control of the tool since the alumina coating has low affinity to workpieces. Moreover, the characteristic color scheme of the AC6030M makes insert corners highly visible, enabling operators to identify used corners even in a dimly lit workplace.

(3) Balance between chipping resistance and wear resistance

In addition to the effect of the boride-titanium compound coating, the AC6030M draws on the thinned alumina layer (thinner by approximately 30% than conventional alumina coating) to improve substantially its chipping resistance. Moreover, to avoid reduced wear resistance resulting from the thinner alumina layer, the composition of Sumitomo Electric Hardmetal's proprietary Super FF Coat has been optimized for improved coating hardness, thereby achieving an excellent balance between chipping resistance and wear resistance.

Figure 5 shows the results of in-house fracture resistance tests, which prove that the AC6030M has at least twice the fracture resistance of the predecessor grade and 1.4 times better fracture resistance than our competitor's product.

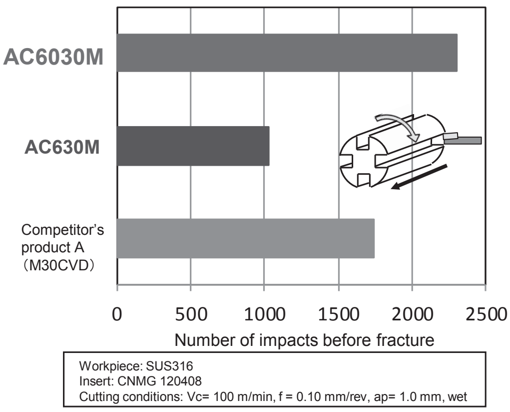


Fig. 5. Cutting performance of AC6030M (fracture resistance evaluation)

Furthermore, **Fig. 6** shows the results of in-house wear resistance testing, which reveals that in comparison with our competitor's product and the predecessor AC630M, the AC6030M exhibits favorable wear resistance performance.

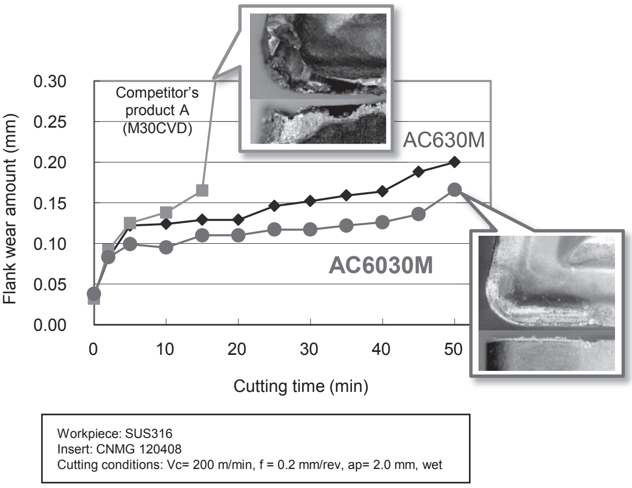


Fig. 6. Cutting performance of AC6030M (wear resistance evaluation)

3-3 Example use of AC6030M

Figures 7 and 8 show example uses of the AC6030M. The example shown in **Fig. 7** involves of the use of the GU-Type chip breaker, which exhibits excellent resistance to chipping and wear, proving that the AC6030M is stable regarding damage to the cutting edge even after three times or more cutting cycles than that of our competitor's product.

Figure 8 shows an example of use with a EG-Type chip breaker. It extends tool life to twice that of the competitor's product even with a 2.5-fold efficiency enhancement (from 60 m/min to 100 m/min in cutting speed Vc and from 0.2 mm/rev to 0.3 mm/rev in feed rate f).

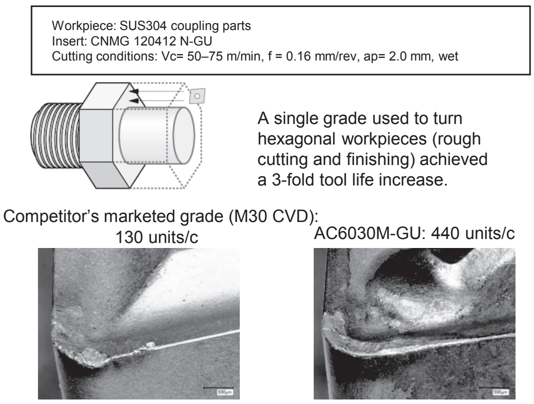


Fig. 7. Example use of AC6030M (with GU-Type)

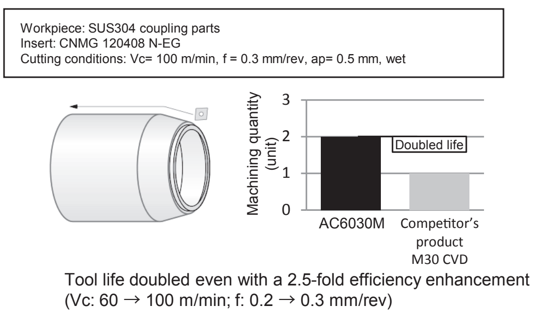


Fig. 8. Example use of AC6030M (with EG-Type)

3-4 AC6040M development goals

To set clear development goals for the AC6040M, an analysis was conducted of the predecessor AC530U to examine damage to used inserts. The analysis results revealed that in many cases crater wear that developed on the tool's cutting face reduced cutting edge strength causing fracture and that a repeated process of work-piece particles welding on and coming off of the cutting edge resulted in the peeling of the coating followed by sudden fracture. Sudden tool fracture is a cause of tool life variability, necessitating irregular tool replacement and therefore manned machining. Otherwise, the need to replace tools after a small volume of machining before the occurrence of fracture will reduce productivity and raise the machining cost. Consequently, the target performance for the AC6040M was planned to exhibit 1.5 times higher resistance to crater wear and fracture than the predecessor grade.

3-5 Development of AC6040M

The AC6040M has been produced using a newly developed cemented carbide substrate and Sumitomo Electric Hardmetal's proprietary PVD coating Absotech Bronze. Absotech Bronze is a coating that has an ultra-multi-layer thin coating structure, the Company's original technology, plus a TiAlSiN coating of a new composition (**Fig. 9**). The coating hardness of Absotech Bronze is approximately 40% higher than that of the conventional TiAlN coating (an increase from 40 GPa to 56 GPa) and exhibits excellent wear resistance.

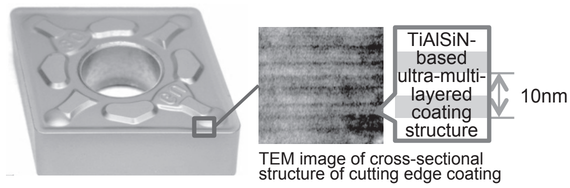


Fig. 9. Exterior and coating structure of AC6040M

(1) Improved resistance to crater wear

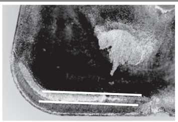
Chips rub against and heat up the cutting face. This heating triggers oxidation and diffusion of the coating and causes crater wear to progress. Consequently, to reduce crater wear, it is important to improve the heat resistance of the coating. Absotech Bronze exhibits excellent heat resistance due to the optimum Ti and Al content in the coating and the addition of Si. **Figure 10** shows oxidation resistance test results for Absotech Bronze and the conventional coating. After exposing sample inserts to high-tempera-

	Before oxidation test	TiAlN film	Coating of predecessor grade	Absotech Bronze
Sample				

Fig. 10. Samples after oxidation test

ture air at 1000˚C for 30 min and slowly cooling them in a room temperature environment, surface conditions of the samples were observed. The observation results revealed the excellent oxidation resistance of Absotech Bronze which was minimally oxidized, while the TiAlN coating and the conventional coating began to become oxidized at 1000˚C.

Next, **Fig. 11** compares damage to cutting faces after 30 min external turning of round SUS316 bars. Improved heat resistance makes Absotech Bronze substantially more resistant to crater wear compared with the conventional coating, as shown in the figure.

	Conventional coating AC530U	Absotech Bronze AC6040M
SUS316 Wear resistance evaluation Damage to cutting face 30 min after turning		

Workpiece: SUS316
Insert: CNMG 120408 N-GU
Cutting conditions: Vc= 150 m/min, f = 0.2 mm/rev, ap= 2.0 mm, wet

Fig. 11. Resistance to crater wear of AC6040M

(2) Improved fracture resistance

The fracture mechanism analysis results for the predecessor AC530U revealed that the coating of the predecessor was worn or peeled away during machining and that as the cemented carbide was exposed, the constituent tungsten carbide (WC) particles fell off, resulting in sudden fracture. Thus we worked on the development of the AC6040M focusing on the structure of cemented carbide. In the newly developed cemented carbide, we revised WC and cobalt (Co) materials and improved sintering conditions to control WC particle growth. As a result, comparing to conventional alloys, a more homogenous alloy structure is formed. The homogenous alloy structure reduces structural defects from which a fracture could start. It also retards crack development in the alloy during machining and reduces detachment of particles, thereby improving fracture resistance. **Figure 12** shows the results of a bending strength test. The strength of the AC6040M has been improved, with the bending strength (deflective strength TRS*3) of the cemented carbide being approximately 20% higher than conventional alloys, as shown in the **Fig. 12**.

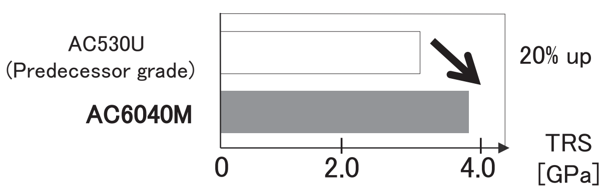
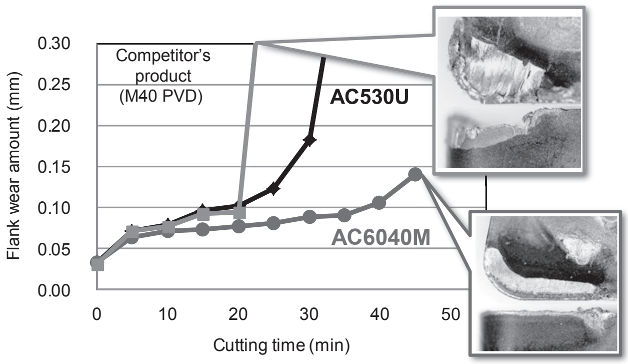


Fig. 12. Bending strength test results for AC6040M

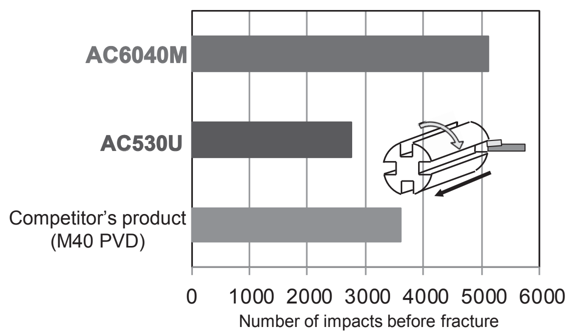
(3) Balance between fracture resistance and wear resistance

The insert grade AC6040M exhibits excellent resistance to wear and fracture due to the novel coating Absotech Bronze and improved cemented carbide substrate, as described above. **Figure 13** shows the results of a wear resistance test. The wear resistance of the AC6040M is about 1.5 times higher than its predecessor and also better than the competitor's product. **Figure 14** shows the results of a fracture resistance test.



Workpiece: SUS316
Insert: CNMG 120408
Cutting conditions: Vc= 150 m/min, f = 0.2 mm/rev, ap= 2.0 mm, wet

Fig. 13. Cutting performance of AC6040M (wear resistance evaluation)



Workpiece: SUS316
Insert: CNMG 120408
Cutting conditions: Vc= 230 m/min, f = 0.23 mm/rev, ap= 0.8 mm, wet

Fig. 14. Cutting performance of AC6040M (fracture resistance evaluation)

The fracture resistance of the AC6040M is more than twice its predecessor's and 1.5 times higher than the competitor's product.

3-6 Example uses of AC6040M

Figures 15 and 16 show example uses of the AC6040M. The example shown in **Fig. 15** involves the Type GU chip breaker. The AC6040M exhibits superior resistance to adhesion and fracture to the predecessor AC530U, achieving a 2.7-fold tool life.

Figure 16 shows use with a Type EG chip breaker. Castings (SCS13) equivalent to SUS304 were machined. In such a machining process, the workpieces cause fracture frequently due to poor casting surfaces and workpiece variability (in structure, hardness, and surface roughness). Under these unstable machining conditions, the AC6040M with Type EG chip breaker exhibited excellent fracture resistance, achieving twice the tool life of the competitor's product.

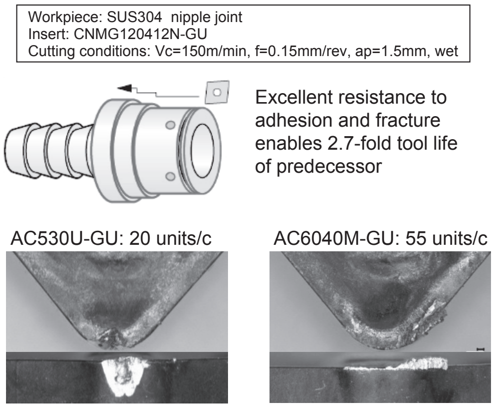


Fig. 15. Example use of AC6040M (with GU-Type)

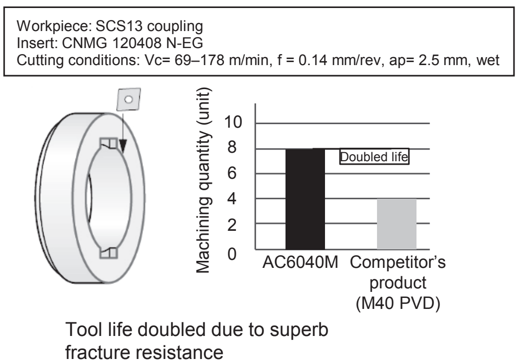


Fig. 16. Example use of AC6040M (with EG-Type)

4. Development of chip breaker EM and its cutting performance

In the machining of stainless steel, chip control and resistance to notch wear are as important factors as tool grade in terms of consistent tool life. Sumitomo Electric Hardmetal has developed the EM-Type chip breaker as a new addition to its existing lineup of chip breakers for stainless steel turning, comprising the finishing chip breaker EF-Type and general-purpose chip breaker EG-Type with improved chip control, resistance to crater wear, and resistance to notch wear.

Two design concepts are applied in the EM-Type chip breaker (**Fig. 17**). It has a smoother flank shape than the predecessor chip breaker MU-Type to ensure improved chip evacuation, and its cutting edge has no irregularities so as to improve in strength. Thus, the EM-Type chip breaker exhibits excellent chip control and resistance to notch wear during rough machining involving higher-feed cutting or a greater cut depth. The development of EM-Type makes our stainless steel machining chip breaker series complete with EF, EG and EM Types. Combinations comprising these chip breakers and the existing chip breaker SU-Type for finishing and general-purpose chip breaker EX, GU and UP Types enable the operator to perform a wider range of stainless steel machining (**Fig. 18**).

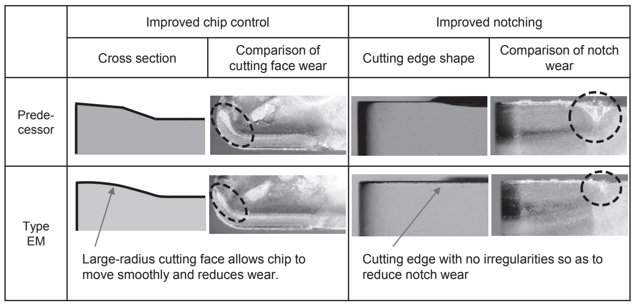


Fig. 17. EM-Type chip breaker design concept

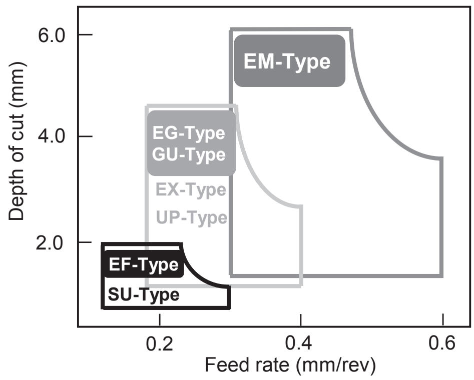


Fig. 18. EM-Type chip breaker for stainless steel machining and applicable ranges for the "E" series

Figure 19 shows an example use of the AC6030M with the EM-Type chip breaker. The improved chip control and cutting edge strength of the EM-Type chip breaker reduce non-cutting edge area fracture and ensure stable machining.

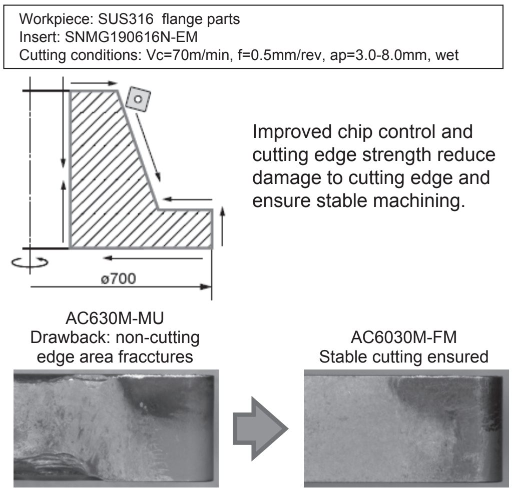


Fig. 19. Example use of AC6030M (with EM-Type chip breaker)

5. Conclusion

The general-purpose grade AC6030M with the new CVD coating Absotech Platinum meets diverse market needs ranging from high-efficiency machining to unstable machining. Its tool life is reliably long under a broad range of machining conditions. The AC6040M grade with the new PVD coating Absotech Bronze for intermittent cutting exhibits great reliability in intermittent cutting and under unstable machining conditions. These grades plus the AC610M for high-speed and high-efficiency cutting provided with the new series of chip breakers for stainless steel machining comprising EF-Type (for finishing), EG-Type (general-purpose), EM-Type (for rough machining) will without doubt help users greatly reduce their machining costs and improve their productivity.

Technical Terms

∗1 Chemical vapor deposition: A chemical process used to produce a thin coating from an intended material in vapor state onto the surface of an object

∗2 Physical vapor deposition: A physical process used to produce a thin coating from an intended material in vapor state on the surface of an object

∗3 TRS (transverse rupture strength): A bending strength index determined in a three-point bending test. Test method: CIS 026 (JIS R 1601/ISO 3327)

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