

Development of Endmills for Milling Hardened Steel Molds and Copper Electrodes

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In recent years, mold manufactures have been prompted to provide low-cost, high-precision products and shorten the delivery time in response to the miniaturization of products and price competition in the global market. Due to this trend, mold manufactures desire to shift their manufacturing method of hardened steel from electric discharge processing with copper electrodes to direct cutting. Sumitomo Electric Hardmetal Corporation has newly released the cubic boron nitride (cBN) BNBR endmills to expand its product lineup for direct cutting. The company has also developed cBN BNBC endmills and diamond-like carbon coated (DLC COAT) SNB2 endmills for copper electrode processing. This paper describes their features and improved performance.

Keywords: cBN, DLC, mold, direct cutting, copper electrode

1. Introduction

In recent years, mold manufacturers have had to meet growing demand for high precision molds, low cost and short delivery time due to the miniaturization of finished products, price competition with overseas companies, and reduced model cycles. In line with these market changes, users have been gradually inclined to shift their machining methods applied to key mold parts (made of hardened steel) from electrical discharge machining, using copper electrodes, to direct cutting. To meet those needs, we have enhanced the lineup of direct-cutting tools and developed new tools for copper electrode machining, still in use as a mainstream machining method.

For direct-cutting endmills, cBN*1 has gradually been replacing conventional carbide alloys, since it is excellent in wear resistance for high-speed milling. In high-speed milling applications at 20,000 rpm or higher, cBN endmills are vastly superior to carbide endmills in terms of tool life and surface finish quality, though in low-speed milling at approximately 10,000 rpm they fail to fully exhibit the material characteristics of cBN: high hardness and high thermal conductivity. cBN, on the other hand, being less tough and more subject to chipping at the cutting edge than carbide, has been considered difficult to exploit its full performance. The radius BNBR type of highly chipping-resistant cBN endmills, shown in **Photo 1**, has been added to the Sumiboron Mold Finish Master series. Featuring application-specific grades and optimal cutting edge design, the newly added cBN endmills provide a solution to the aforementioned problem.

Regarding copper electrode machining tools, tool manufacturers have launched micromachining tools that feature CrN-coated carbide. Many of them are multi-purpose tools designed with application to other workpiece materials in mind. **Photo 2** shows SNB2-type Aurora Coat (DLC*2) long-neck, ball-nose endmills, developed as micromachining tools specifically for copper electrodes, and the BNBC-type Sumiboron Mold Finish Master. This paper reports on the features of these tools and application examples.



Photo 1. BNBR-type Sumiboron Mold Finish Master



Photo 2. SNB2-type and BNBC-type endmills for copper electrode milling

2. Direct-Cutting Tools “BNBR-Type Sumiboron Mold Finish Master”

2-1 Features

The BNBR type has the following features:

- (1) cBN grade resistant to both wear and chipping enables high-speed milling of hardened materials and substantially reduces machining time.

- (2) Cutting edge design for optimizing sharpness and chipping resistance ensures long tool life.
- (3) Wiper edge yields clean finished surfaces and significantly reduces polishing process time.
- (4) Tool life approximately 10 times longer than that of coated carbide tools enables mold completion with a single endmill.
- (5) Enables high-precision machining with corner R accuracy of $\pm 5 \mu\text{m}$.

These features make the BNBR type ideal for precision machining of hardened steel molds.

2-2 Milling performance

(1) Effects of wiper edge

Figure 1 shows the tool profile of the BNBR type incorporating a wiper edge as the end cutting edge, along with milled surface quality effects of wiper edge presence or absence. Machining conditions were: workpiece material: STAVAX (52 HRC), spindle speed: 20,000 rpm, feed rate: 800 mm/min, cut depth in the z-direction: 0.03 mm, cut depth in the radial direction: 0.7 mm, oil mist and tool 2 mm diameter and 0.5 mm corner radius. Tools with and without a wiper edge were used to machine flat surfaces. The milled surfaces were then compared and evaluated in terms of surface roughness.

Comparison of the two types showed that the tool with a wiper edge yielded 1.6 to 1.7 times better surface smoothness than the tool without a wiper edge, proving that the wiper edge produces a high-quality milled surface.

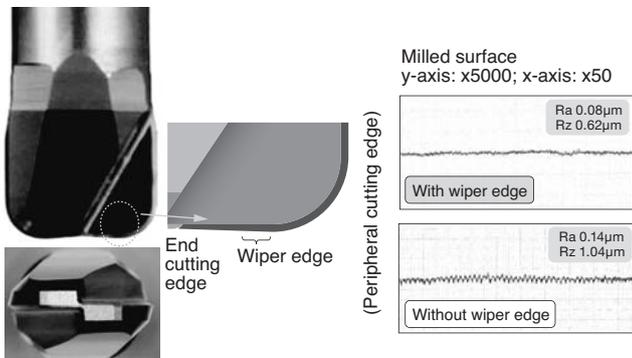


Fig. 1. Quality of milled surfaces produced using tools with/without wiper edge

(2) Comparison with coated carbide endmill

Figure 2 compares and evaluates damaged cutting edges of cBN and coated carbide endmills, after machining a flat surface on STAVAX (52 HRC). Machining conditions were: spindle speed of 20,000 rpm and feed rate of 800 mm/min for cBN, and spindle speed of 4,800 rpm and feed rate of 120 mm/min for the coated carbide endmill. Cut depth in the z-axis direction and that in the radial direction were 0.03 mm and 0.7 mm, respectively, for both cBN and coated carbide endmills.

The tool life of cBN, defined as 0.03 mm wear at the

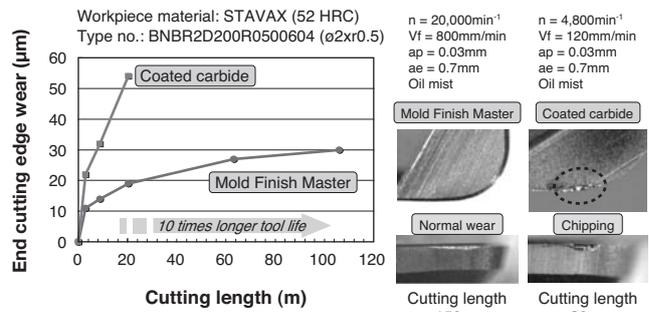


Fig. 2. Comparison of cBN and carbide endmills (1)

end cutting edge before chipping, is approximately 10 times longer than that of the coated endmill, despite high cutting speed and high feed rate conditions.

Figure 3 compares and evaluates cBN and coated carbide in terms of flat surface machining, with workpiece material of hardened material HAP 40 (66 HRC). The tool life of cBN, determined on the basis of end cutting edge wear, is approximately 10 times longer than that of the carbide endmill, as in the aforementioned analysis.

The long cBN tool life reduces tool change frequency and eliminates milled surface height differences resulting from tool change. Reduced cutting edge wear also improves dimensional accuracy and lessens time required for polishing in the subsequent process. Consequently, in comparison with carbide endmills, cBN endmills - though higher in unit price - reduce lead time and machining cost.

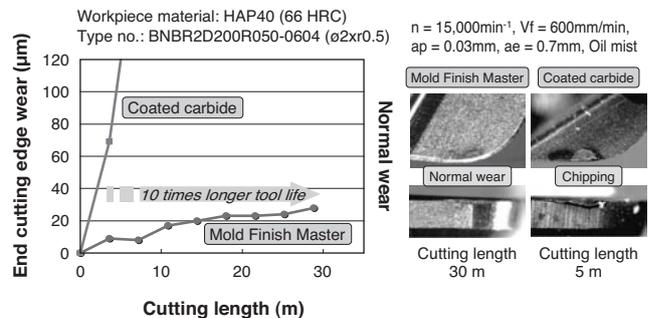


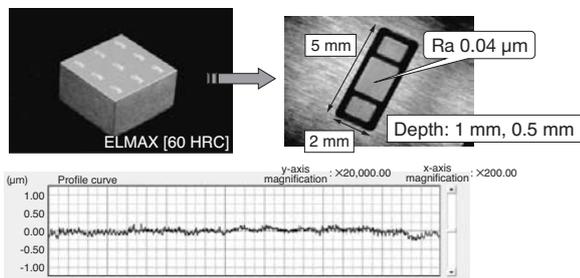
Fig. 3. Comparison of cBN and carbide endmills (2)

2-3 Application examples

Figure 4 shows an example of mold milling by Mold Finish Master.

The workpiece shape represents an LED lens mold. In this example, a radius BNBR type directly cut a hardened solid material for roughing at a high spindle speed of 40,000 rpm, taking advantage of the chipping resistance of the radius BNBR type. The workpiece was finished with a ball-nose BNBP type.

The pitch accuracy of the milled slot walls was less than 0.002 mm, indicating that the endmill had only slight edge wear. The roughness of the machined surface was favorable at Ra 0.04 μm .



Milling process	Tool	Speed min ⁻¹	Feed rate mm/min	XY (mm)	Z (mm)	Remnant (mm)	Milling duration
Contour roughing	ø0.5 R0.1 Radius endmill BNR2D050R010-0154	40000	400	0.1	0.01	0.05	15 min
Contour roughing	R0.2 Ball-nose endmill BNP2R020-0124	40000	400	0.05	0.02	0.01	20 min
Contour finishing	R0.2 Ball-nose endmill BNP2R020-0124	40000	400	0	0.02	0	12 min
Linear finishing	R0.2 Ball-nose endmill BNP2R020-0124	40000	400	0.03	0	0	8 min

Fig. 4. Application example

3. Tool for Copper Electrode Milling “SNB2-Type Aurora Coat (DLC) Long-Neck Ball-Nose Endmill” and “BNBC-Type Sumiboron Mold Finish Master”

3-1 Features

(1) SNB2-type Aurora Coat (DLC)

Compared with CrN coatings currently and commonly used as coating for endmills designed for copper electrodes, Aurora Coat is harder and more wear resistant, has extremely smooth coated surfaces and provides excellent sliding performance. However, one drawback of this coating is its low resistance to heat. To overcome this problem, the tool profile shown in Fig. 5 was developed specifically for milling copper electrodes. A sharp-cutting, large rake angle is used to reduce heat during cutting. The edge profile, featuring a large chip pocket combined with a low-frictional coefficient DLC coat, enables stable milling with superb chip evacuation.

(2) BNBC-type Sumiboron

The characteristics (strengths/weaknesses) of cBN include higher hardness and thermal conductivity, yet lower toughness than carbide and high-speed steel. To meet user demand for copper electrode milling tools with longer tool life, a high-cBN content grade was used. Figure 5 shows features of the tool profile, including increased edge strength and sharpness. Having improved in chipping resistance, wear resistance and sharpness, the high-cBN content grade provides stable workpiece surface quality for an extended period of time.

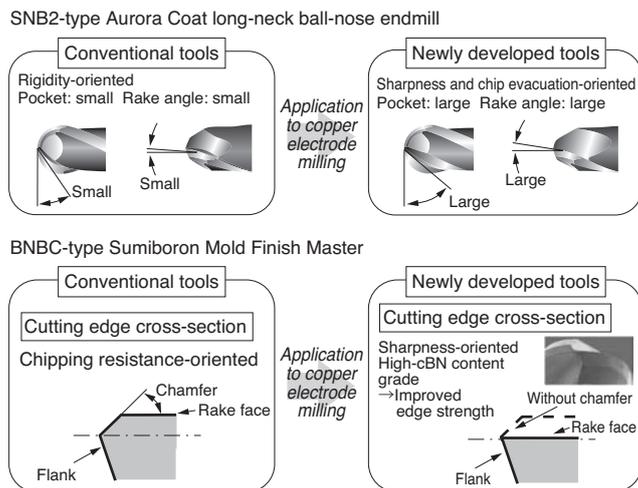


Fig. 5. Features of tool profile

3-2 Milling performance of SNB2 and BNBC types

The SNB2 and BNBC types and workpiece material, tough pitch copper, were used to conduct various milling performance tests. Figure 6 shows tool wear resulting from side milling. Figure 7 shows cutting resistance and surface roughness.

Regarding tool wear, the SNB2 type exhibited good tool life, five times longer than the CrN-coated carbide at a cut length of 40 m, the criterion for tool wear being flank wear of 0.01 mm. The SNB2 type can be used continuously. The BNBC type showed extremely favorable results and can be used continuously; its tool life being 38 times that of the CrN-coated carbide at a cut length of 300 m.

As for cutting resistance, the SNB2 type exhibited the lowest resistance, marking an 11% reduction from that of the CrN-coated carbide. Accordingly, the tool was designed to reduce deflection and provide high-precision milling. The BNBC type showed higher cutting resistance than carbide tools, due to an edge profile factor (rake angle).

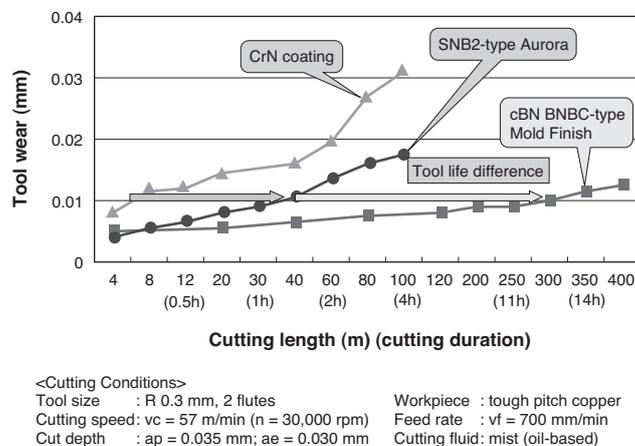


Fig. 6. Tool wear

<Cutting Conditions>
 Tool size : R 0.3 mm, 2 flutes
 Cutting speed: $v_c = 57 \text{ m/min}$ ($n = 30,000 \text{ rpm}$)
 Cut depth : $a_p = 0.035 \text{ mm}$; $a_e = 0.030 \text{ mm}$
 Workpiece : tough pitch copper
 Feed rate : $v_f = 700 \text{ mm/min}$
 Cutting fluid: mist (oil-based)

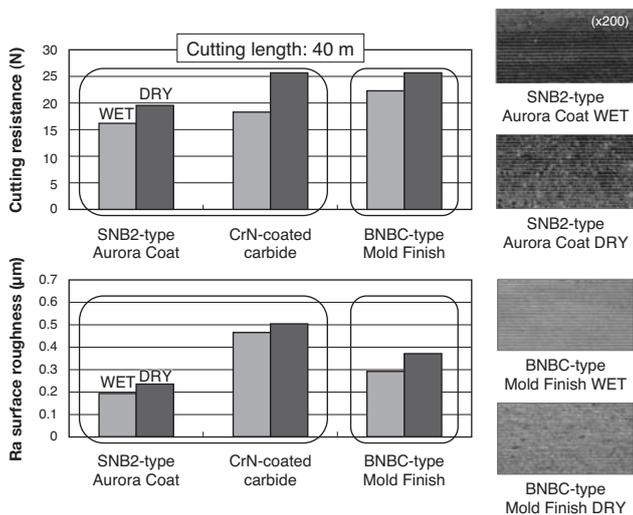


Fig. 7. Cutting resistance and surface roughness

Meanwhile, regarding surface roughness, the result for the SNB2 type was favorable, showing a 50% improvement over the CrN-coated carbide (wet milling). The BNBC type delivered a 37% improvement over the CrN-coated carbide. Both SNB2- and BNBC-type tools showed little difference in performance under wet and dry conditions. All things considered, however, they are suitable for wet milling, though superior to CrN-coated carbide tools even in dry milling.

These excellent results were achieved thanks to the characteristics of the DLC coating, the cBN base material and tool profiles. Figure 8 shows quality of milled surfaces resulting from different cutting conditions (speed and feed per tooth). At a less-than-optimal speed of 20,000 rpm, both tools presented cutter marks resembling damaged surfaces, and left burrs, though lightly. However, when the speed was 30,000 rpm or higher, the result was satisfactory with minimum cutter marks and no burrs. Considering sur-

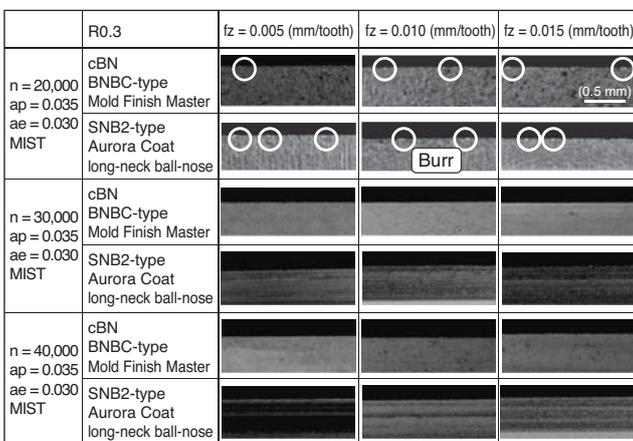
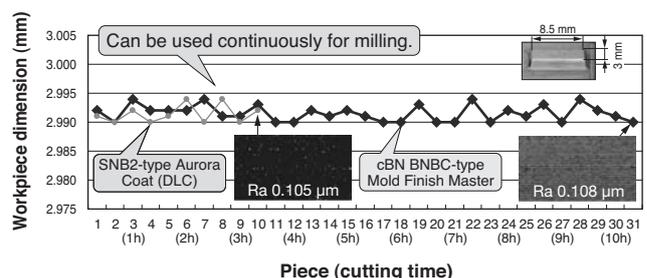


Fig. 8. Workpiece surface quality, by cutting conditions

face roughness, the best set of test conditions were 30,000 rpm and a feed per tooth of $f_z = 0.01$ mm/tooth ($v_f = 600$ mm/min). Accordingly, the SNB2 and BNBC types are suitable for use at high speeds.

3-3 Application example

Figure 9 shows dimensional variation occurring in the course of cutting many pieces of an electrode shape (3 x 8.5 x 1.2 mm). With the SNB2 type, dimensional variation was 4 µm resulting from milling 10 pieces (cutting length: 110 m), while with the BNBC type, dimensional variation was 4 µm after milling 31 pieces (cutting length: 341 m). Consequently, these types can be used continuously for a long period of time, achieving milling with stable dimensional accuracy.



<Cutting Conditions>
 Tool size : R 0.2 mm, 2 flute
 Workpiece : tough pitch copper
 Cutting speed : $v_c = 38$ m/min
 ($n = 30,000$ rpm)
 Feed rate : $v_f = 400$ mm/min
 ($f_z = 0.007$ mm/tooth)
 Cut depth : $a_p = 0.01$ mm; $a_e = 0.01$ mm
 Cutting fluid : mist (oil-based)

	Dimensional variation	Tool wear
cBN BNBC-type Mold Finish Master (31 pieces, L = 341 m)	4 µm	5 µm
SNB2-type Aurora Coat (DLC) (10 pieces, L = 110 m)	4 µm	10 µm

Fig. 9. Workpiece dimensional variation

4. Conclusion

The following conclusions have been drawn from milling performance tests.

- 1) The BNBR-type Sumiboron Mold Finish Master has a tool life 10 times longer than carbide endmills. High-quality milled surfaces delivered by the BNBR type reduce polishing time.
- 2) The tool life of the SNB2-type Aurora Coat long-neck ball-nose endmill is five times longer than that of CrN-coated endmills in copper electrode milling. The SNB2 type is also excellent in both cutting resistance and surface roughness, thereby enabling milling with stable dimensional accuracy.
- 3) The BNBC-type Sumiboron Mold Finish Master provides a tool life 38 times longer than CrN-coated endmills. It also performs well in terms of surface roughness, and can be used continuously for an extended time.

These results reveal that the three tools provide higher

accuracy, greater efficiency and longer tool life, as compared with conventional tools, and are believed to improve productivity.

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Technical Terms

- *1 cBN (Cubic boron nitride): The hardest material; second only to diamonds. Compared with diamonds, cBN resists heat and reacts less with iron.
- *2 DLC (Diamond like carbon): A hard amorphous film made up of allotropes of carbon.

References

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