# Development of "SUMIBORON" BN1000/BN2000 for Hard Turning

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With the expanding use of PCBN cutting tools in hard turning applications, there is an emerging demand for new PCBN tools in such applications as cutting of small parts, where cutting speed is limited under 80m/min, and cutting of die steel or high speed steel. In order to meet this demand, "SUMIBORON" BN1000/BN2000 have been developed using high-purity ceramics binder. BN1000/BN2000 with impurities significantly diminished show excellent cutting performance, wear resistance and breakage resistance. In this report, the cutting performance and cutting applications of BN1000/BN2000 are described.

Keywords: PCBN, hardened steel, high precision, high efficiency, cutting force

## 1. Introduction

### 1-1 PCBN tools

cBN (cubic boron nitride) has features of hardness next to diamond and lower reactivity with iron than diamond. This cBN is difficult to be sintered independently, and the CBN sintered compact (or PCBN = polycrystalline cubic boron nitride) produced by sintering cBN together with a binder comprising metals and ceramics is extensively used for machining ferrous metals as cutting tools.

Sumitomo Electric Industries, Ltd. developed a PCBN using ceramics as a binder for the first time in the world and commercialized "SUMIBORON," PCBN tools for hardened steel machining(1). Hardened steel had been machined till then by grinding by the use of a grinding wheel, which used to be the only possible means. Cutting by PCBN tools achieves higher efficiency and higher accuracy as compared to this grinding process, and therefore, was adopted in place of grinding process primarily by the automotive industry where particularly mass production was required and at present, has become a general machining method for hardened steels.

In order to meet the needs of still higher efficiency and higher accuracy machining in the automotive industry, Sumitomo Electric Industries, Ltd. developed and put on market PCBN tools SUMIBORON BNC Series(2)-(4). BNC Series has improved the heat resistance and toughness required in high-speed high-efficiency machining by coating ceramics with still higher heat resistance than cBN onto the PCBN with superb toughness, and has thereby the tool performance evolved. Consequently, BNC Series have made high-efficiency roughing possible not only of automotive components but also even large-size bearings, construction components, and others, and applications in this field have been expanding.

### 1-2 Need of uncoated PCBN tools

As cutting of hardened steel by PCBN is popularized, not only above-mentioned high-speed high-efficiency machining but also needs of high-accuracy machining have been actualized for hydraulic components used for engine fuel injection systems as well as electronic components and other small components.

These components are smaller than gears and driveline components in automobiles, and therefore a low cutting speed results. In the low cutting speed region (not more than about 80 m/min), the cutting force increases, and ceramics coating with lower strength than PCBN may indicate abnormal damage. Consequently, the performance of the PCBN itself must be improved.

Furthermore, these components have the strength increased on a quest to improve the environmental performance and are tended to become difficult to be cut. Difficult-to-cut hardened steels contain large proportions of carbides such as $Cr_2C_3$, VC, MoC and others with high hardness, and ceramics coating with hardness lower than CBN lacks hardness when these materials are cut. Consequently, in cutting of hardened steel with high-hardness, performance of PCBN itself must be improved, too.

In addition, sophistication has been implemented not only on small components but also on all components, and component shapes tend to increase complexity and become thin-walled. In machining of complicated profiles, sufficient tool rigidity and chuck rigidity may be unable to be secured, and in addition in the case of thin-walled components, rigidity of the workpiece itself is lowered. Under such circumstances, mechanical loads applied to tool cutting edges by vibrations during cutting increase, and as a result, ceramics coating may be abnormally damaged as in the case described above. Consequently, under low-rigidity cutting environment, too, the performance of PCBN itself must be improved.

In order to meet these needs, new PCBN tools BN1000/BN2000 were developed in an effort to improve the performance of PCBN itself. This paper introduces these tools.

## 2. Features of BN1000/BN2000

As described in the beginning, PCBN comprises high-strength cBN and ceramics binder primarily comprising TiN or TiCN with outstanding heat resistance. As the cBN content increases, the strength and toughness are improved and material grade with an emphasis placed on breakage resistance is obtained, while as the cBN content is decreased, the heat resistance is improved and the material grade with an emphasis placed on wear resistance is obtained. In this development, the ratio of cBN to the ceramics binder was not changed to improve the performance with both breakage resistance and wear resistance simultaneously satisfied, and efforts were made to improve the properties of ceramics binder.

Conventionally, the ceramics binder contained traces of impurities in the manufacturing process or in the process of mixing with cBN. These impurities provided lower strength and heat resistance than ceramics, and therefore, served as crack initiation points to lower the breakage resistance or wear resistance. Therefore, the manufacturing process of ceramics binder was renovated, and a new process was adopted. This made it possible to manufacture a high-purity ceramics binder containing impurities not more than 1/10 the conventional. The new PCBN with this high-purity ceramics binder applied achieved dramatic performance improvement with the balance between breakage resistance and wear resistance maintained.

**Table 1** shows the compositions of new PCBN grades, BN1000 and BN2000 with the high-purity ceramics binder applied, and **Fig. 1** shows the positioning of the new CBN grade SUMIBORON for hardened steel cutting purposes. BN2000 is the succession grade of BN250 and is a general-purpose grade that can be used for continuous to interrupted cutting. BN1000 is the succession grade of BNX10 and is the grade with greater emphasis placed on wear resistance than BN2000.

**Table 1.** Compositions and physical properties of BN1000 and BN2000

| Grade | cBN content [vol%] | cBN particle size [ m] | Binder | Hardness [GPa] | TRS [GPa] |
|---|---|---|---|---|---|
| Conventional grade: BN250 | 50-55 | 2 | TiN | 31-34 | 1.00-1.10 |
| **BN2000** | 50-55 | 2 | High-purity TiN | 31-34 | 1.05-1.15 |
| Conventional grade: BNX10 | 40-45 | 3 | TiCN | 27-31 | 0.80-0.90 |
| **BN1000** | 40-45 | 1 | High-purity TiCN | 27-31 | 0.9-1.00 |

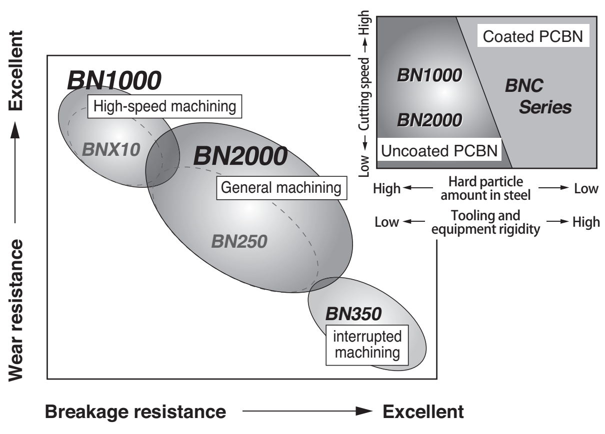



**Fig. 1.** Positioning of Uncoated PCBN "SUMIBORON" for machining of hardened steels

## 3. Performance of BN2000 for General Machining of Hardened Steels

### 3-1 Continuous cutting

**Figure 2** shows the results of comparing with conventional grades in continuous cutting of carburized hardened steels. In the initial stages of cutting, the flank wear rate of BN2000 is nearly equal to that of conventional grades. In this regard, however, after cutting 5 km, in the conventional grades, the cutting edge was chipped due to propagation of crater wear, whereas no breakage was observed with BN2000, demonstrating that BN2000 was able to cut still longer distance. It is assumed that applying the high-purity ceramics binder improved the heat resistance of sintered compact and exhibited the effect of suppressing propagation of crater wear.

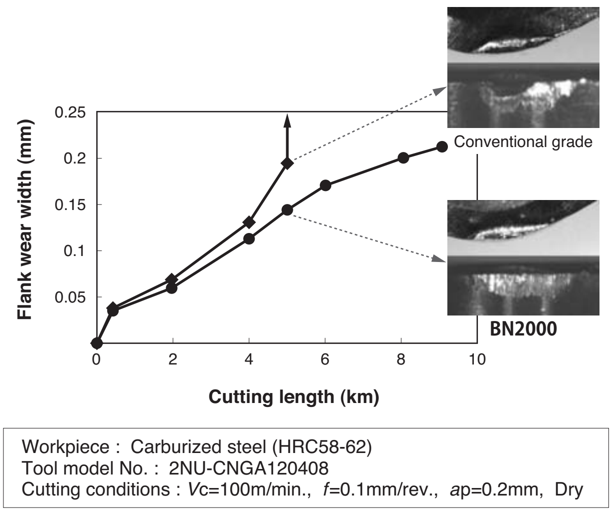
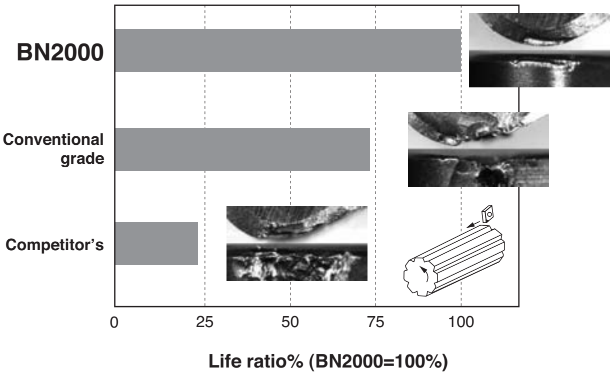



**Fig. 2.** Continuous cutting evaluation results of BN2000

### 3-2 Interrupted cutting

**Figure 3** shows the results of performance evaluation in interrupted cutting of carburized hardened steels. For the work material, as shown in the figure, that provided with a V-letter shape groove was used. In this evaluation, it was able to be confirmed that BN2000 provides longer life than conventional grades. Based on the foregoing, it was




Workpiece : Carburized steel HRC58-62 8V-grooved material
Tool Model No. : 2NU-CNGA120408
Cutting conditions : *Vc*=150m/min., *f*=0.1mm/rev., *ap*=0.2mm, Dry

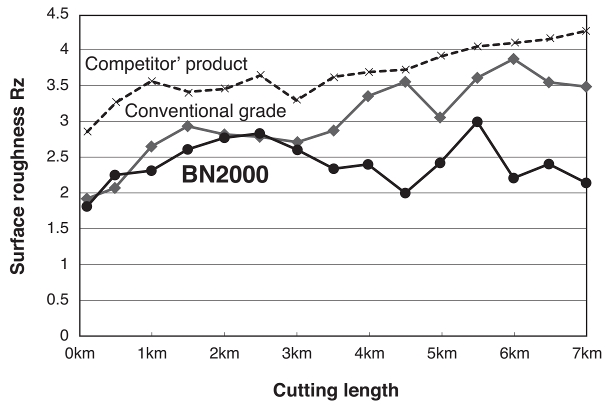
**Fig. 3.** Interrupted cutting evaluation results of BN2000

confirmed that BN2000 provided outstanding wear resistance and breakage resistance as compared to the conventional grade.

**3-3 Surface roughness**

Next, in order to evaluate the performance in high-accuracy machining, cutting evaluation was performed with surface roughness standard 3.2z assumed. The workpiece used was carburized hardened steel. **Figure 4** shows the results. BN2000 indicated stable surface roughness from the initial stages of cutting, demonstrating that BN2000 exhibited the life longer than that of the conventional grade and that of a competitor.

The surface roughness is decided by the profile of the end cutting edge being transferred to the finish surface. It is assumed that when notch wear is developed in the end cutting edge, level differences are generated in the end cutting edge, and the surface roughness is aggravated. BN2000 has the binder strength improved by applying the high-purity binder, and thus development of notch wear may possibly be suppressed.




Workpiece : Carburized steel (HRC58-62)
Tool Model No. : 2NU-CNGA120408
Cutting conditions : *Vc*=100m/min., *f*=0.08mm/rev., *ap*=0.2mm, Dry

**Fig. 4.** Surface roughness evaluation results of BN2000

**3-4 Cutting of high speed tool steels**

In order to evaluate the BN2000 performance on more difficult-to-cut hardened steels discussed in Section 1, cutting was performed on high speed tool steel.

**Photo 1** shows microstructures of various hardened steels. The carburized steels, which are most popularly used for automotive components etc., contain only a few percent of carbides and the microstructure is composed nearly with martensite only. On the other hand, die steel and high speed tool steel contain not less than 10% carbides for improving the strength and wear resistance, indicating that carbides are scattered about in the microstructure.

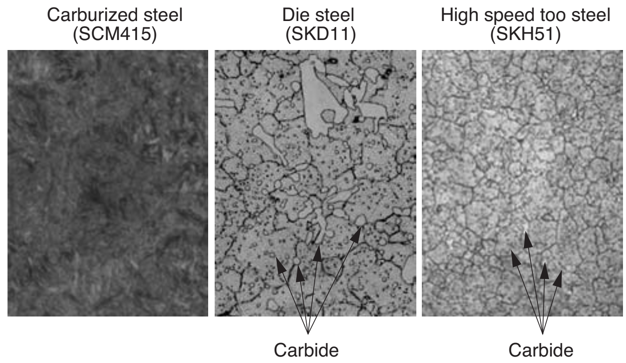
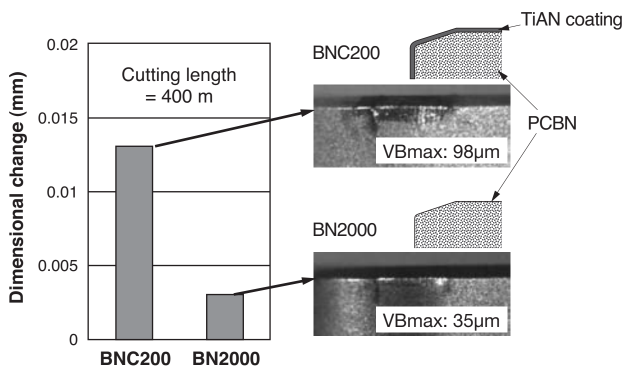



**Photo 1.** Microstructure photomicrographs of hardened steel

**Figure 5** shows the results of measuring dimensional changes of workpieces in the initial stages of cutting (cutting length = 400 m) using BN2000 and BNC200 of coated cBN to cut high speed tool steels. In BN2000, only a slight dimensional change was recognized but BNC200 indicated large dimensional changes. Based on the cutting edge photograph shown in **Fig. 5** on the right, BNC200 generated a larger wear rate, indicating that this dimensional change




Workpiece : High speed tool steel (HRC60)
Tool Model No. : 2NU-CNGA120408
Cutting conditions : *Vc*=100m/min., *f*=0.05mm/rev., *ap*=0.05mm, wet

**Fig. 5.** Dimensional change data at the time of cutting high speed tool steels

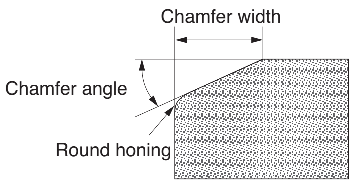
Table 2. Compositions of BNC200 and BN2000

| Grade | Coating (film thickness) | Sintered cBN | | | | |
|---|---|---|---|---|---|---|
| | | cBN content (vol%) | cBN particle size (m) | Binder | Hardness (GPa) | TRS (GPa) |
| **BNC200** | TiAlN (2μm) | 65-70 | 4 | TiN | 33-35 | 1.10-1.20 |
| **BN2000** | None | 50-55 | 2 | High-purity TiN | 31-34 | 1.05-1.15 |

was associated with the wear. **Table 2** shows the compositions of BN2000 and BNC200. BNC200 is composed of the base material with greater emphasis placed on breakage resistance than BN2000 and ceramics coating with outstanding wear resistance. Ceramics coating exhibits outstanding heat resistance but, on the other hand, provides lower hardness than cBN. Consequently, it is assumed that the ceramics coating is abraded by high hardness carbides contained in a large quantity in high speed tool steel and is unable to thoroughly exhibit the heat resistance, and as a result, generates large wear. For this kind of application, uncoated PCBN tool would be suitable.

**3-5 BN2000 cutting edge preparation**

To the cutting edge of the PCBN tool, it is general practice to chamfer or hone the cutting edge surface as shown in **Fig. 6** in order to secure the breakage resistance at the time of cutting. For BN2000, two cutting edge preparation types, LT and HS, are kept in stock in addition to the standard type so that BN2000 is able to meet various applications as a general-purpose grade. This is shown below **Fig. 6**.




| Cutting edge preparation | Chamfer angle [°] | Chamfer width [mm] | Round honing |
|---|---|---|---|
| Standard type | 25 | 0.12 | Honed |
| LT type | 15 | 0.12 | Not honed |
| HS type | 35 | 0.12 | Honed |

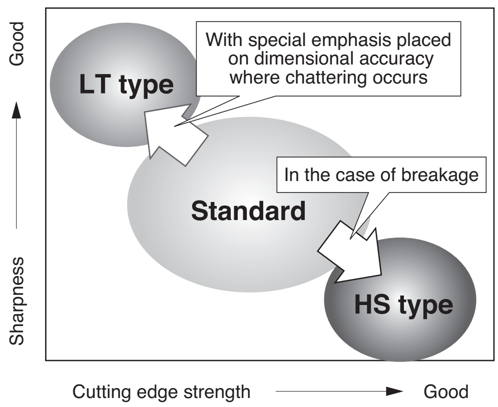
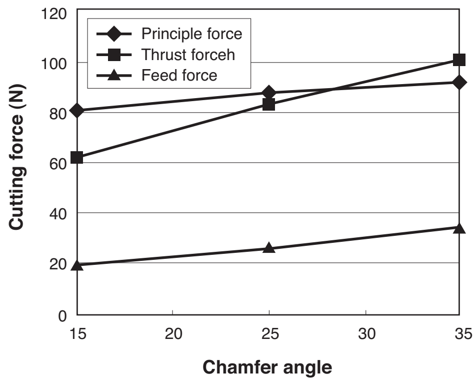



Fig. 6. Cutting edge preparation of BN2000

**Figure 7** shows changes of cutting force by chamfer angles. As clear from the figure, as the chamfer angle is decreased, the cutting force is able to be reduced, and this is effective where dimensional accuracy is mandatory or where chattering is generated in small-hole boring, etc. Consequently, in such a case, the LT type is applied.

On the other hand, as the chamfer angle is increased, the cutting force increases, but the stress generated in the vicinity of the cutting edge is alleviated, and breakage in interrupted cutting could be reduced. Consequently, where breakage is generated in interrupted cutting etc., the HS type is applied.



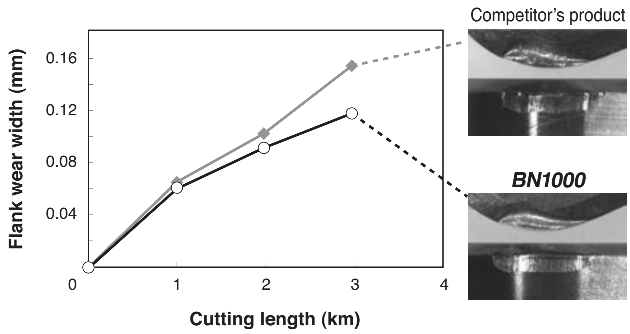

Workpiece : Carburized steel (HRC60)
Chip : NU-TPGW110308
Holder : WBPT220
Cutting conditions : *Vc*=150m/min., *f*=0.1mm/rev., *ap*=0.2mm, Dry

Fig. 7. Correlation between cutting chamfer angle and cutting force

## 4. Performance of BN1000 for High-Speed Machining of Hardened Steels

**4-1 Continuous cutting**

Next introduced is the cutting performance of BN1000. **Figure 8** shows the results of continuous cutting



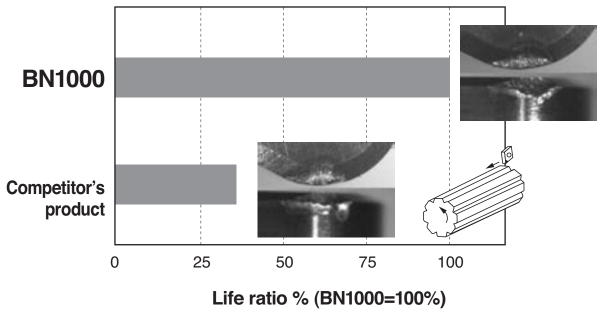

Workpiece : SUJ2 (HRC62)
Tool Model No. : 2NU-CNGA120408
Cutting conditions : *Vc*=150m/min., *f*=0.1mm/rev., *ap*=0.2mm, Dry

Fig. 8. Continuous cutting evaluation results of BN1000

evaluation of bearing steel. It was able to be confirmed that BN1000 provided outstanding wear resistance as compared to that of the competitor's. In BN1000, for which a greater emphasis is placed on the wear resistance, high-purity TiCN ceramics binder is applied. Consequently, BN1000 exhibits the most outstanding wear resistance of the uncoated PCBN.

**4-2 Interrupted cutting**

**Figure 9** shows the results of evaluating the breakage resistance. In the interrupted cutting evaluation, same as in the case of BN2000, workpieces with a V-letter groove provided in carburized hardened steels were used. The competitor's product rapidly propagated crater wear and broke but BN1000 slowly propagated crater wear and enabled cutting about 3 times before breakage. With the foregoing description, it was confirmed that BN1000 exhibits outstanding wear resistance and breakage resistance as compared to the competitor's.

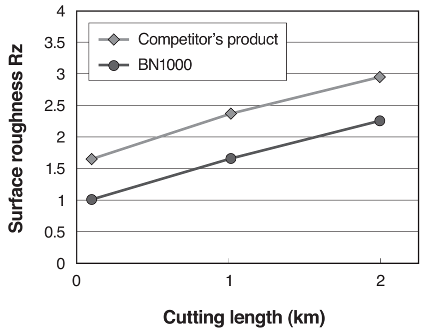



Workpiece : Carburized steel (HRC58-62) 8V-grooved material
Tool Model No. : 2NU-CNGA120408
Cutting conditions : *V*c=150m/min., *f*=0.1mm/rev., *a*p=0.2mm, Dry

**Fig. 9.** Interrupted cutting evaluation results of BN1000

**4-3 Surface roughness**

**Figure 10** shows the evaluation results of high-accuracy machining with the surface roughness standard 3.2z assumed. This compares high-accuracy machining results in the initial stages of cutting only, but BN1000 indicated satisfactory surface roughness as compared to the competitor's product. The competitor's product degraded the surface roughness to about 3 μm at the time of cutting 2 km, but in BN1000, it was able to confirm that machining with the surface roughness not more than 3.2z could be achieved.




Workpiece : Carburized steel (HRC58-62)
Tool Model No. : 2NU-CNGA120408
Cutting conditions : *V*c=150m/min., *f*=0.08mm/rev., *a*p=0.10mm, Dry

**Fig. 10.** Surface roughness evaluation results of BN1000

## 5. Application Regions of BN1000/BN2000

**Figure 11** shows the application region of uncoated PCBN grades in hardened steel machining.

BN2000 is a general-purpose grade that can be used for a wide region from continuous cutting to interrupted cutting. As compared to the conventional grade, the upper

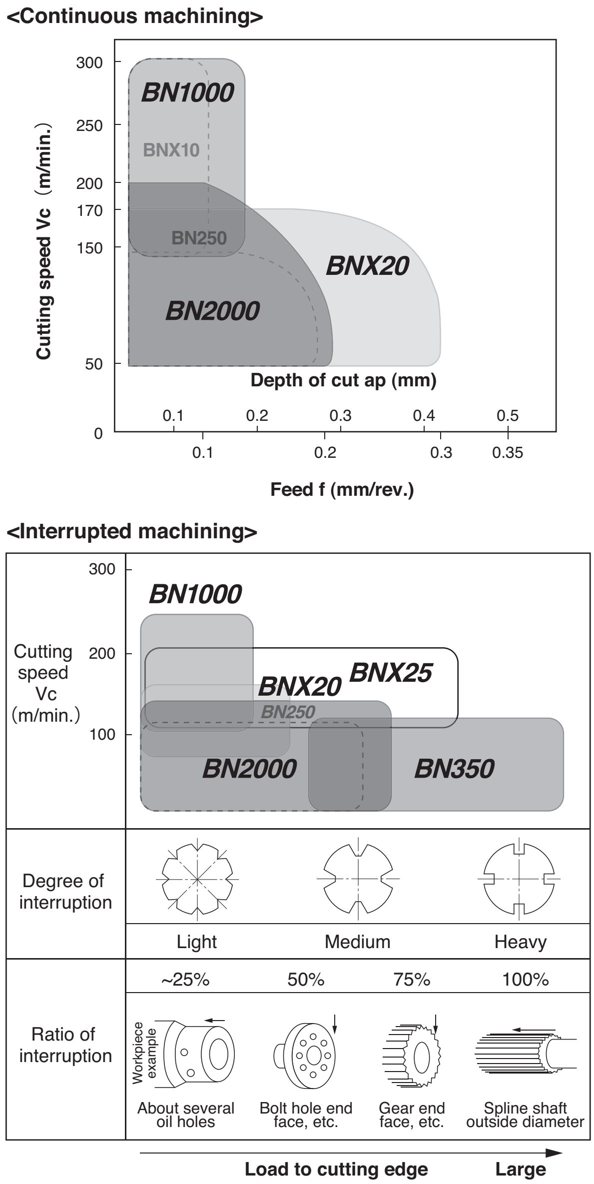
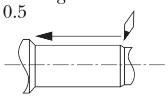
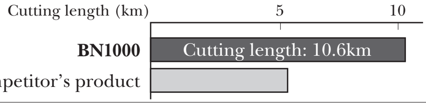
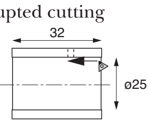
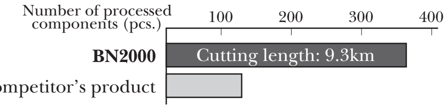
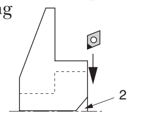
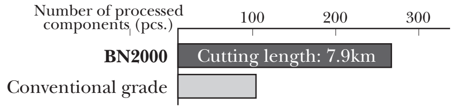
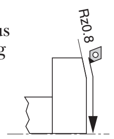
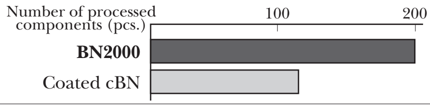
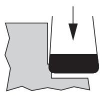
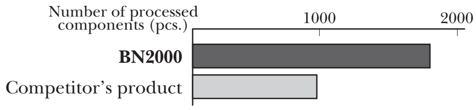
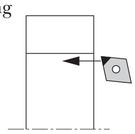
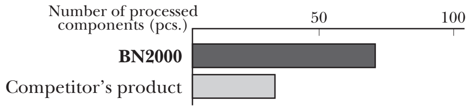



**Fig. 11.** Application regions of BN1000/BN2000

**Table 3.** Cutting examples of BN1000/BN2000

| No. | Tooling | [1] Component name<br>[2] Material | Tool model No. | *Vc* = cutting speed<br>*f* = feed<br>*ap* = depth of cut | Use results |
|---|---|---|---|---|---|
| 1 | Outside finish machining<br>Surface roughness<br>Ra = 0.5<br> | [1] Oil pump shaft<br>[2] S55C induction hardened | NU-VBGW160404<br>**BN1000** | *Vc* = 195m/min.<br>*f* = 0.04mm/rev.<br>*ap* = 0.18mm.<br>Wet | • BN1000 achieved twice as long as life of competitor's product in Ra0.5 machining.<br> |
| 2 | Inside diameter interrupted cutting<br> | [1] Outer guide<br>[2] SCM415H Carburized steel | NU-TPGW110308<br>**BN2000** | *Vc* = 135m/min.<br>*f* = 0.1mm/rev.<br>*ap* = 0.15mm.<br>Dry | • BN2000 achieved triple as long as life free of any chipping.<br> |
| 3 | End face interrupted cutting<br> | [1] Pulley<br>[2] SCM415H Carburized steel | 2NU-DNGA150408<br>**BN2000** | *Vc* = 150m/min.<br>*f* = 0.1mm/rev.<br>*ap* = 0.2mm.<br>Dry | • BN2000 has crater breakage suppressed and doubles the life.<br> |
| 4 | End face continuous machining<br> | [1] Plunger<br>[2] SKD11 | 2NU-DNGA150408<br>**BN2000** | *Vc* = 0-150m/min.<br>*f* = 0.03~0.25 mm/rev.<br>*ap* = 0.04mm.<br>Dry | • Where cutting speed is extremely low, surface roughness is stabilized more for BN2000.<br> |
| 5 | Grooving<br> | [1] Shaft<br>[2] SCM420H Carburized steel | Special grooving tool<br>**BN2000** | *Vc* = 100m/min.<br>*f* = 0.08mm/rev.<br>*ap* = 0.25mm.<br>Dry | • Superb wear resistance is exhibited in grooving.<br> |
| 6 | Roughing<br> | [1] Roller bushing<br>[2] Carburized steel | CNMA120412<br>**BN2000** | *Vc* = 100m/min.<br>*f* = 0.13mm/rev.<br>*ap* = 3.0mm.<br>Dry | • ap=3 mm roughing achieved by regrinding type.<br> |

limit of the cutting speed is increased to as high as 200 m/min, and the interrupted cutting region is increased, too.

BN1000 is the high-speed cutting grade and is applied where the wear resistance lacks with BN2000, and is able to machine materials at high speed up to 300 m/min with primary emphasis placed on continuous finish machining. The breakage resistance is improved from the conventional grade BNX10, and BN1000 is able to be applied to interrupted cutting with small loads.

## 6. Cutting Examples

**Table 3** shows the cutting examples of BN1000 and BN2000.

No. 1 is a case of BN1000 in high-speed continuous cutting. In the Table, the cutting part only is shown, but since actual work forming is complicated, the cutting environment is a long tool overhung and low tool rigidity from the viewpoint of tooling. Consequently, it is not the coated PCBN tool but BN1000 that enabled extension of tool life.

No. 2 and No. 3 are life extension examples of BN2000 in interrupted cutting. No. 2 is high-accuracy machining with 15-μm dimensional tolerances. Even minor chipping degraded the dimensional accuracy and shortened tool life. As BN2000 provides chipping resistance superior to the competitor's, it achieved tool life as much as 3 times. No. 3 used to cause crater wear to advance and resulted in breakage, but applying BN2000 with outstanding heat resistance doubled the tool life.

No. 4 is die steel with high hardness of hardened steels, and is the case in which low-speed cutting was performed at the end face center. The tool life judgment criterion is the surface roughness of Ra 0.8, and in the case of BNC200, wear was disturbed and surface roughness was degraded, whereas BN2000 indicated stable surface roughness and achieved about double the tool life of BNC200.

No. 5 is the case of a grooving. With the competitor's tool, the life was reached due to degraded dimensional accuracy resulting from wear development, but BN2000 exhibited outstanding wear resistance without causing breakage and achieved about double the life.

No. 6 is the case of roughing with a depth of cut as large as 3 mm, where a regrind type was used. In roughing, the cutting edge temperature increased, crater wear was developed and the life was expired but by BN2000 with superb heat resistance, the tool life was nearly doubled.

## 7. Conclusion

As described above, by the development of BN1000/BN2000, extension of tool life has been achieved in cutting small articles, such as fuel injection components, or high-hardness hardened steels, and in cutting under low rigidity environment. By adding BN1000/BN2000 to the conventional coated PCBN tools, it is expected that cutting by PCBN tools is applied in machining of a still wider range of hardened steels and will contribute to increased manufacturing efficiency and cost reduction.

* SUMIBORON, SUMIBORON BNC, BNC200 are trademarks or registered trademarks of Sumitomo Electric Industries, Ltd.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