New Grade “SUMIBORON BN7115” for Finishing Sintered Ferrous Alloys and Cast Iron

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The cubic boron nitride (cBN) cutting tool “SUMIBORON” is mainly composed of cBN particles that have low activity with iron, and has high hardness and high thermal conductivity next to diamond, contributing to productivity improvement and cost reduction in the finishing of difficult-to-cut ferrous materials. In the past decade, the automotive industry has strongly driven the shift to hybrid electric vehicles and electric vehicles, which requires higher precision and higher efficiency in machining of sintered ferrous alloys and cutting tools with stable performance and longer tool life for cast iron. The authors have successfully developed a new grade “SUMIBORON BN7115” for finishing these materials. BN7115 employs a high-purity cBN particles and new binder consisting of Co-Al-Cr-WC to improve the bonding strength between cBN particles, thereby achieving good resistance to wear and breakage. BN7115 is expected to solve problems such as a degradation of the cuting surface of sintered ferrous alloys caused by the dropout of cBN particles and chipping of edges caused by thermal shock during cutting cast iron.

Keywords: high cBN content grade, the bonding strength between cBN particles, sintered ferrous alloys, cast iron, finish machining

1. Introduction

Cubic boron nitride (cBN) has hardness and thermal conductivity second only to diamond, and exhibits a low affinity with ferrous metals, which is a property not found in diamond. Through the supply of “SUMIBORON” cBN sintered tools (CBN tools), which can be used for the finish machining of ferrous materials such as hardened steel, sintered ferrous alloys*1 (sintered alloys), and cast iron, Sumitomo Electric Industries, Ltd. has helped its customers improve machining efficiency and accuracy, as well as reduce equipment costs. Since CBN tools can also be used for dry machining, the Company has also contributed to saving energy and reducing industrial wastes such as grinding sludge.(1),(2) A high cBN content grade is composed of a metal binder and cBN particles that are directly bonded to each other. The cBN content of this compact exceeds 90% by volume. Due to its high hardness and high thermal conductivity, this sintered compact demonstrates high performance in the high-speed machining of sintered ferrous and cast iron in which the tool is damaged mainly due to mechanical wear (abrasive wear).

The functions of sintered alloys manufactured by powder metallurgy*2 have been upgraded through the improvement of mechanical properties, complication of shapes, and higher precision by taking advantage of the high degree of freedom in material design. In particular, with the recent spread of hybrid vehicles, the use of high-efficiency drive systems such as electric variable valve timing (VVT) is increasing, and the sintered alloys making up these systems are required to be harder and more accurate in dimension. For example, nickel and molybdenum are added to these sintered alloys to suppress dimensional strain during quenching. However, the addition of these metals shortens tool service life. In addition, CBN tools can be used at a speed 10 times or more faster than cemented carbide tools*3 for machining cast iron. However, in the milling*4 of the mating surfaces of engine blocks and oil pumps, for example, CBN tools are exposed to the environment where the coolant fluid used in the preceding drilling process remains on the machined part (“residual WET” for short) and thermal shock can cause thermal cracking of the tools, resulting in sudden chipping. As a means of solving such problems, we have developed the new grade “SUMIBORON BN7115”. Achieving a high level of balance between wear resistance and breakage resistance, the new grade is suitable for the finish machining of sintered alloys and cast iron. This paper describes the development background, features, and cutting performance of the new grade.

2. Challenges in the Machining of Sintered Alloys

For a CBN tool used for machining conventional sintered alloys, the appearance of burrs on, the white turbidity of, and the deterioration of the machined surface are determinant factors for the tool life. In order to inquire into the damage mechanism of cutting tool edge, the surface and cross-section of the worn tool were observed. The results are shown in Fig. 1. This figure shows the progress of markedly uneven striated flank wear. Further, a high-magnification observation of the surface and cross-section of flank was performed to analyze the wear pattern in detail. As a result, it was observed that the metallic binder phase had disappeared from the worn tool, leaving cBN particles on the surface. In the cross-section of the cutting edge, voids were observed inside approximately 3 μm from the surface. These voids were considered to have been formed as a result of the disappearance of the binder. The above results suggested that wear of a CBN tool used for machining a sintered alloy progresses by the mechanism shown in Fig. 2. According to the Fig. 2, a low-hardness binder is first scraped off by high-melting-point metals or carbides contained in the sintered alloy, and it adheres to the scraping traces. Then the heat generated during machining causes the adhered sintered alloy and metal binder to diffuse and react with each other, and the metal binder is eluted from the inside of the tool, leaving only the skeleton of cBN particles on the cutting edge surface. When the cutting stress imparted to cBN particles left on the cutting edge surface eventually exceeds the bonding strength between cBN particles ("inter-particle bonding strength" for short), the particles come off the CBN tool, and the wear progress. A CBN tool is judged to have reached the end of its service life when the shape of the cutting edge ridge collapses due to the progress of wear, and as a result, generates burrs on the machined part, white turbidity on the machined surface, and deteriorates the surface finish accuracy. Therefore, increasing the inter-particle bonding strength, improving thermal conductivity, and suppressing heat generation by the cutting edge are the challenges for improving tool performance.

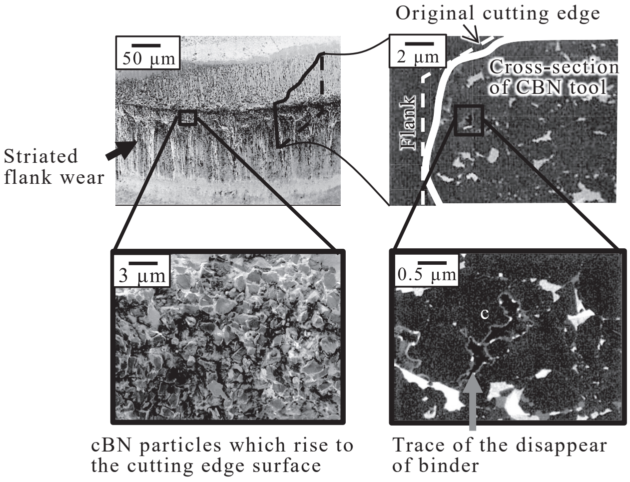


Fig. 1. Damage pattern of cutting edge in the machining of a sintered alloy

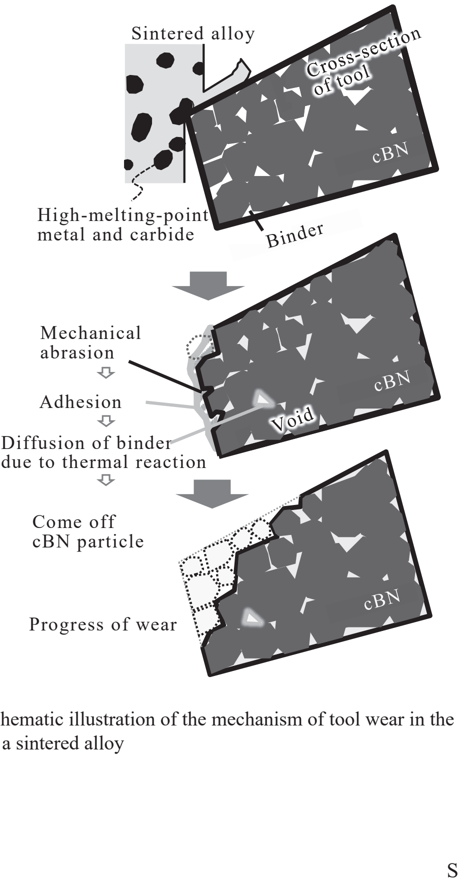


Fig. 2. Schematic illustration of the mechanism of tool wear in the machining of a sintered alloy

3. Challenges in the Machining of Cast Iron

In the machining of cast iron, it has been reported that when the cutting edge is heated to 1,000°C or more under an ultra-high-speed condition, sudden breakage occurs. In particular, in interrupted cutting such as milling, the tool surface is rapidly cooled, but the decrease in temperature inside the tool does not follow the same rate, so that tensile stress occur in the tool surface. Therefore, when the tool repeats a process of machining and not machining, thermal cracking occurs on the tool surface. This phenomenon becomes especially noticeable in a residual WET environment. It is known that the thermal shock breakage resistance coefficient R'(3) of a hard material is expressed by the following equation.

$$R' = \frac{k\sigma_T(1-\nu)}{E\alpha}$$

where k: thermal conductivity (W/m・K), σ_T: bending strength*5 (GPa), ν: Poisson's ratio, E: Young's modulus (GPa), and α: linear expansion coefficient (1/K).

From the above equation, the challenge for improving the performance of tools in the milling of cast iron is to reduce thermal shock-induced sudden breakage by providing tools with a high level of balance between high thermal conductivity and high bending strength.

4. Features of BN7115

4-1 Specification and material properties

BN7115 is a high cBN content sintered compact, and a special measure has been implemented for this compact to strengthen the bonding between the cBN particles, the main components of this compact. Table 1 shows the specifications and properties of BN7115 and conventional CBN tool products (conv. CBN). The cBN powder raw material of a conv. CBN is black in color since the Mg compound used as a synthesis catalyst remains as an impurity. On the other hand, amber-colored high-purity cBN particles, which are synthesized using a Li compound as a catalyst, have high bending strength and toughness since they contain very few residual impurities that interfere with the bonding of cBN particles. Because of these properties, BN7115 shows excellent stability even when machining difficult-to-cut cast iron.(4) With regard to the binder, we have newly developed a Co-Al-Cr-WC alloy in which Cr is homogeneously dispersed in a conventional Co-Al-WC alloy to strengthen the bond between cBN particles. We dramatically increased the bonding strength between cBN particles by sintering these high-purity cBN particles and the new binder together at ultra-high pressure and temperature, which is the Company's world-leading process. Thus, we have succeeded in the development of an ideal CBN sintered body having

Table 1. Specifications and material properties of BN7115

Material			Conv. CBN	**BN7115**
Specifications	cBN	Purity	Low	High
		Content (vol%)	90 – 95	90 – 95
		Particle size (µm)	1	1
	Binder		Co-Al-WC	Co-Al-Cr-WC
Properties	Hv hardness (GPa)		41 – 44	**41 – 44**
	Bending strength (GPa)		2.0 – 2.1	**2.2 – 2.3**
	Fracture toughness (MPa•mm$^{1/2}$)		7 – 9	**10 – 11**
	Thermal conductivity (W/m•K)		110	**115**

excellent bending strength, fracture toughness,*[6] and thermal conductivity.

4-2 Bonding strength between cBN particles

With the aim of directly evaluating the bonding strength between cBN particles without taking into account the effect of the binder, we fabricated a CBN sintered compact with a skeletal structure by removing the binder with acidic treatment, and evaluated its properties. Figure 3 shows scanning electron micrographs of the sintered body before and after the acidic treatment. Before the acidic treatment, the binder appeared white, but after the acidic treatment, the material was eluted and left voids. As a result, a structure composed of only cBN particles was fabricated. The hardness, bending strength, and thermal conductivity of the new CBN sintered compact were all higher than that of the conv. CBN, as shown in Fig. 4. Considering that the cBN content of the new and conventional sintered compacts was equal, an increase in bonding strength between cBN particles improved the mechanical properties and the thermal conductivity. Figure 5 shows the result of machining a sintered alloy with the sintered compact with a skeletal structure. As shown in this figure, the cutting edge of the conv. CBN was chipped conspicuously, while the damage to the cutting edge of BN7115 was very slight. This result verified that enhancing the bonding strength between cBN particles improve the performance of BN7115 in the machining of sintered alloys.

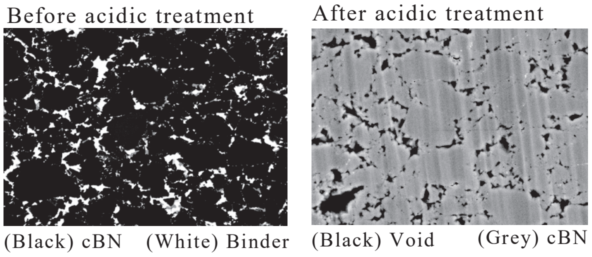
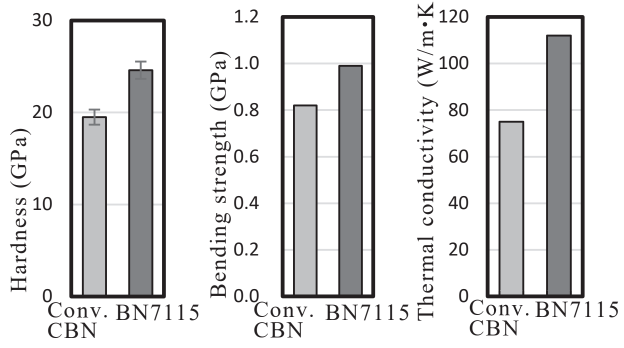


Fig. 3. Structure of CBN sintered compact before and after acidic treatment



*The bending strength was measured using a small test piece.

Fig. 4. Properties after acidic treatment

Part Material: Sintered alloy
(equivalent to SMF4040, Continuous)
Tool Cat. No.: 2NU-CNGA120408
Edge Specification: Standard
Cutting Conditions: V_c = 200 m/min,
f = 0.10 mm/rev,
a_p = 0.20 mm,
Dry

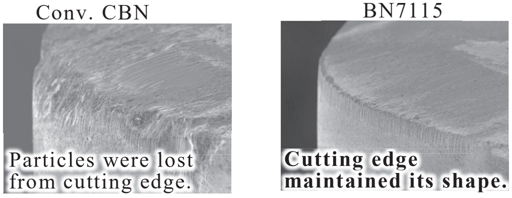


Fig. 5. Cutting edge after machining a sintered alloy with CBN tool containing no binder

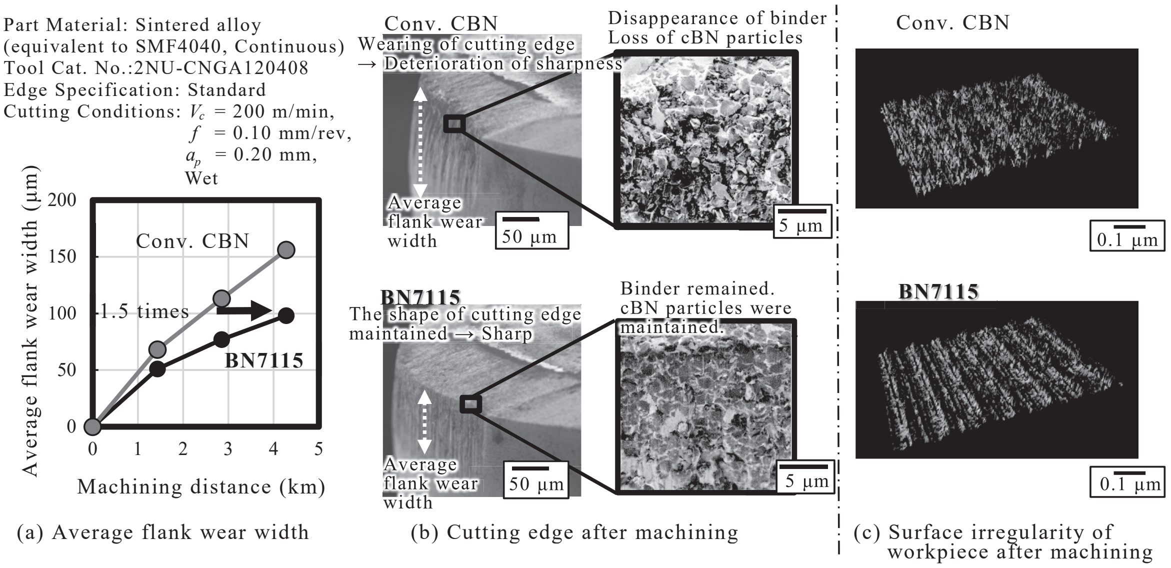
5. Cutting Performance of BN7115

5-1 Machining of sintered alloys

The evaluation results for the tool performance of BN7115 in the machining of a sintered alloy are shown in Fig. 6 (a). It was found from the progress of the average flank wear with the machining distance that the wear of BN7115 was 40% lower than that of conv. CBN. Assuming that a tool reaches the end of its service life when the width of wear reaches 100 µm, we confirmed that BN7115 has a tool service life 1.5 times longer than that of conv. CBN. It was also found from the detailed observation of the cutting edge ridge that BN7115 remarkably reduced the loss of cBN particles, thereby keeping the cutting edge ridge very sharp and maintaining the smoothness of the area of the flank wear even after the machining (Fig. 6 (b)). As a result, as shown in Fig. 6 (c), the quality of the machined surfaces was dramatically improved. Subsequently, the end face of a high-strength sintered alloy (equivalent to FLA-07C2M) was machined intermittently in order to check the breakage resistance of BN7115. As a result, the breakage resistance of BN7115 was 4 times higher than that of conv. CBN, as shown in Fig. 7.

5-2 Machining of cast iron

We compared the machining performance of BN7115 with those of a conv. CBN [A] and [B] by milling cast iron in a simulated residual WET environment. The cast iron with a pearlitic structure was used as the workpiece, and the time until each tool was chipped by thermal cracking (breakage life) was measured. As a result, the conv. CBN [A] and [B] were chipped due to thermal cracking, while BN7115 extended the breakage life by significantly reducing thermal cracking (Fig. 8 (a)). As shown in Fig. 8



(a) Average flank wear width (b) Cutting edge after machining (c) Surface irregularity of workpiece after machining

Fig. 6. The performance of BN7115 in machining a sintered alloy

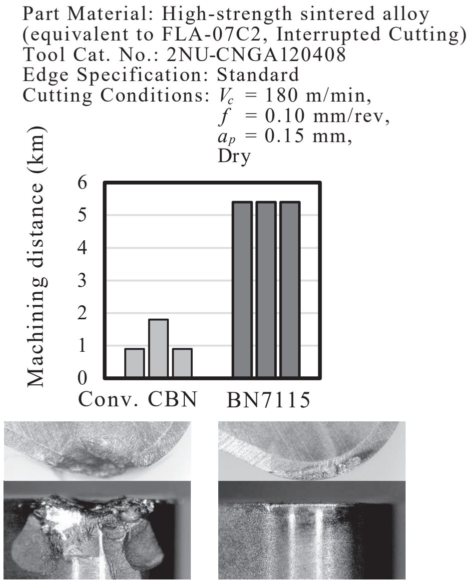
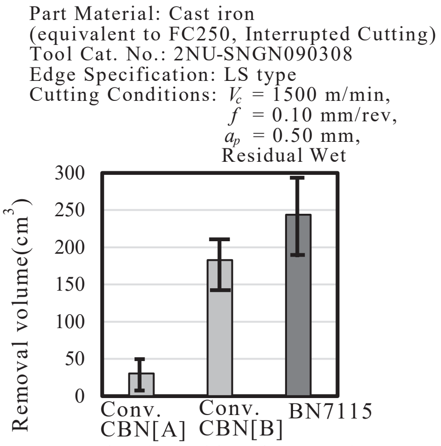
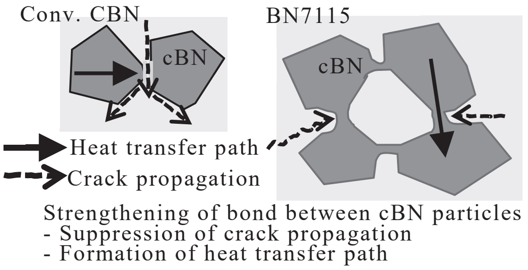


Fig. 7. Evaluation of breakage resistance in the machining of a high-strength sintered alloy



(a) Evaluation of breakage resistance in the machining of cast iron



(b) Performance improvement mechanism

Fig. 8. Breakage resistance of BN7115 in the machining of cast iron and performance improvement mechanism

(b), these results verified that BN7115 has extremely high thermal shock resistance since this new tool material forms a heat transfer path by strengthening the bond and effectively suppressing crack propagation.

6. Application Area of BN7115 and Example of Practical Use

The application area of BN7115 is shown in Fig. 9. BN7115 is recommended for use for finish machining since this tool material can maintain the tool's sharpness and excellent machined surface quality for a long time as described above. For example, BN7115 demonstrates its performance in the end-face finishing of automotive VVT parts and oil pump rotors, as well as in the flange machining of valve sheet ring. With the bending strength and toughness which are superior to those of conv. CBN, this new tool material indicates machining stability of high-strength sintered alloys parts such as electrically driven VVT parts while extending their service life. BN7115 also exhibits high performance for the high-speed machining of cast iron since this material achieves a high level of balance between thermal conductivity and bending strength as already described. Furthermore, BN7000 is recommended for the machining applying a high load exerted to a cutting edge.

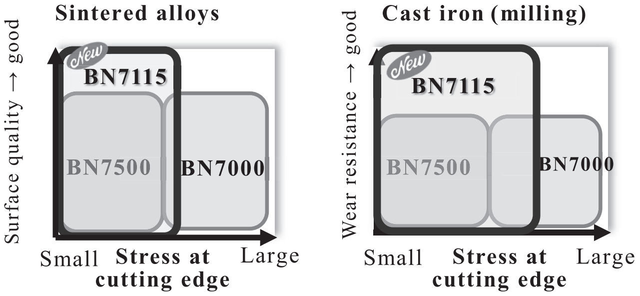
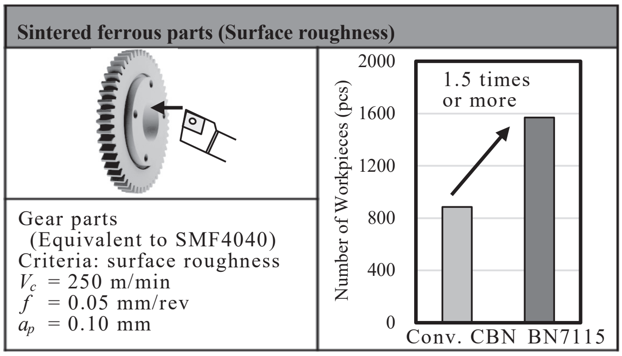
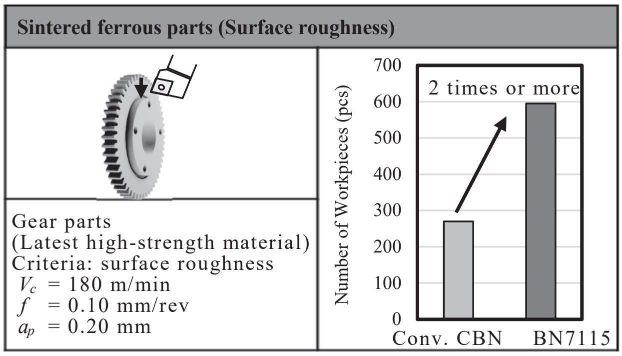


Fig. 9. Application area of BN7115

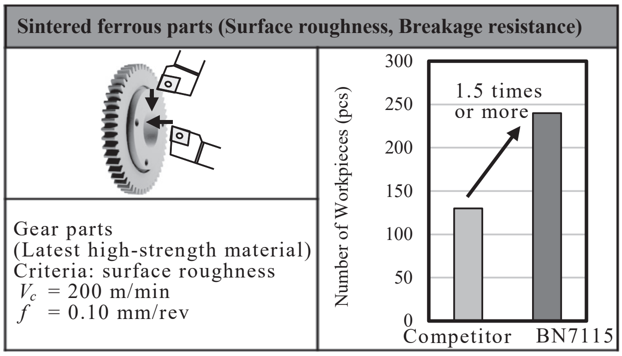
Figure 10 shows an example of the practical use of BN7115. Because of its outstanding mechanical and thermal properties, BN7115 maintained the cutting edge shape for a long period of time in the machining of the conventional sintered alloy while extending the service life as defined on the basis of the finished surface roughness (surface roughness life) to 1.5 times or more that of conventional tool materials (a). Further, in the intuerrupted machining of the end face of high-strength sintered alloy gear parts, BN7115 extended the surface roughness life to 2 times or more that of conventional tools (b), and its breakage resistance was superior to that of CBN tools made by a competitor (c). Furthermore, in the machining of cast iron (in a residual WET environment), no thermal cracking was generated in all cutting edges of BN7115, verifying that the thermal shock resistance of the new tool had been improved noticeably. Therefore, we confirmed that BN7115 has a tool service life 1.3 times longer than that of conventional tools (d). As described above, in the machining of conventional sintered alloys, high-strength sintered alloys and the high-speed machining of cast iron, BN7115 achieved a higher efficiency and longer service life.



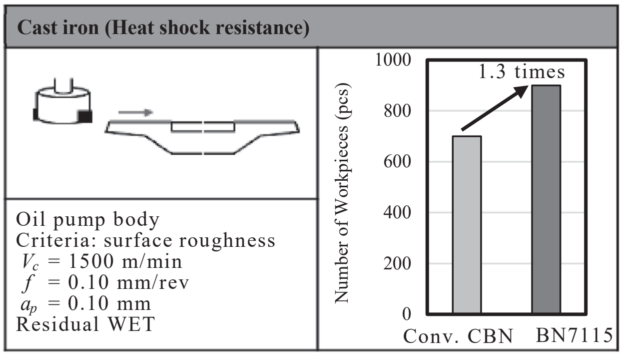
(a) Example of machining sintered ferrous parts



(b) Example of machining high-strength sintered ferrous parts



(c) Example of machining high-strength sintered ferrous parts



(d) Example of machining cast iron parts

Fig. 10. Examples of practical use

7. Conclusions

Use of "SUMIBORON BN7115" for sintered alloys and cast iron finishing applications stabilizes and extends tool service life by suppressing burrs and white turbidity, which are challenges in the machining of sintered alloys, and by minimizing sudden breakage of the cutting edge attributable to heat crack in the high-speed machining of cast iron. With its highest material strength and thermal conductivity among SUMIBORON products, the potential use of BN7115 is not limited to the machining of sintered alloys and cast iron. The new material will also demonstrate its performance in applications where high material strength is required, such as strong interrupted machining of hardened steel and hard milling. Thus, BN7115 is expected to expand the range of possible applications in the future.

- SUMIBORON is a trademark or registered trademark of Sumitomo Electric Industries, Ltd.

Technical Terms

∗1 Sintered ferrous alloy: A ferrous alloy made by sintering fine powder of several kinds of metals after compression-forming them into a desired shape.

∗2 Powder metallurgy: A technique for manufacturing parts by sintering powder after forming it into a desired shape. This technique is advantageous in manufacturing parts that are difficult to cast because of their particular structures, compositions, or shapes.

∗3 Cemented carbide tool: A cutting tool made by sintering tungsten carbide which is hard material and cobalt, which is a binder.

∗4 Milling: A method for forming flat surfaces and grooves with a rotatable tool by fixing the workpiece to a movable table.

∗5 Bending strength: Stress at which the test piece is broken in a bending test.

∗6 Fracture toughness: An index of stress load required to propagate cracks in a material containing a defect that will cause crack generation.

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