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High-efficiency and high-quality grinding of high-speed steel using ultrafine-crystalline cBN abrasive grit

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Abstract
This paper presents the high-efficiency and high-quality grinding using an ultrafine-polycrystalline cBN (cBN-U) abrasive grit developed from pBN of high purity by direct conversion sintering at high pressure and high temperature. A series of high-efficiency surface plunge grinding experiments of high-speed steel was conducted using the cBN-U wheel and conventional monocrystalline cBN wheel. The result showed that cBN-U wheel had a very high wear resistance as compared with the monocrystalline cBN wheel. Hence, the grinding ratio in grinding with the cBN-U wheel was higher than 10 times of that in using monocrystalline cBN wheel. Moreover, it was confirmed that the estimated grinding wheel life using the cBN-U wheel, based on the finished surface roughness, was much longer than that of the monocrystalline cBN wheel.

Keywords: ultrafine-polycrystalline cBN abrasive grit, high-efficiency and high-quality grinding, high-speed steel, grinding wheel life, grinding ratio

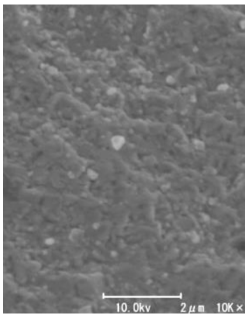
1. Introduction

Cubic boron nitride (cBN) grinding wheels are becoming widely used for the grinding of various engineering materials, such as steels, cast irons, and superalloys. To enhance the grinding performance of cBN wheels, we have developed a new type of polycrystalline cBN abrasive grit by direct transformation from pyrolytic boron nitride, which was produced by a chemical vapor deposition process [1]. This cBN abrasive grit possesses an ultrafine crystal structure composed of submicron-sized primary crystal grains. We call this grit "ultrafine-polycrystalline cBN grit" ("cBN-U grit" for short). Because the wear resistance of cBN-U grit is superior to those of conventional monocrystalline and polycrystalline cBN abrasive grits, it is expected to be applied in a wide range of industrial fields that are manufacturing machine tools, robots, optical electronic apparatus, aerospace instruments, biomedical devices, and so on.

The purpose of this study is to clarify the feasibility of high-efficiency and high-quality grinding using ultrafine-polycrystalline cBN-U grit. A series of surface plunge grinding experiments of high-speed steel using cBN-U vitrified wheel was conducted, and its grinding performance was compared with that of a representative conventional monocrystalline cBN vitrified wheel.

2. Experimental procedure

cBN-U grit has an ultrafine polycrystalline structure composed of primary crystal grains with a grain size smaller than 500 nm, as shown in **Figures 1** and **2**. The tensile fracture strength of cBN-U grit is about 3.5 times higher than that of conventional monocrystalline cBN grit. Before grinding experiments, dressing of cBN wheel was precisely performed using a rotary diamond dresser (Dressing wheel: SD40Q75M) equipped with an AE sensor under the following conditions: peripheral dressing speed 16.5 m/s, peripheral wheel speed ratio 0.5, dressing lead 0.1 mm/rev, dressing depth of cut 2 μm × 5 times.



----2μm---
Figure1, SEM image of fracture surface of cBN-U grit

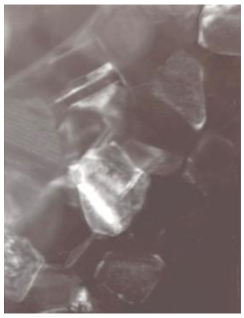

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Figure 2, TEM image of crystal structure of cBN-U grit

To elucidate the potential of cBN-U grit for high-efficiency and high-quality grinding, surface plunge grinding experiments using vitrified wheels made of cBN-U grit and typical monocrystalline cBN (denoted by cBN-M) grit with a mesh size of #80/100 were carried out, and the difference in grinding performance between both wheels was compared under the grinding conditions listed in **Table 1**.

Table 1 Grinding conditions

Grinding method		Surface plunge grinding (up cut)			
Grinding wheel		CBN80L100V Dimensions: $200^{\phi}\times10^{t}$ mm			
cBN grain		Ultrafine-polycrystalline cBN (cBN-U) Monocrystalline cBN (cBN-M)			
Peripheral wheel speed	V_s	33 m/s			
Wheel depth of cut	a	10 μm			
Work speed	v_w	0.15	0.25	0.35	m/s
Stock removal rate	Z'	1.5	2.5	3.5	mm^3/mm/s
Grinding fluid		Soluble type (JIS W-2-2), 2 % dilution			
Workpiece		High-speed steel (JIS SKH51) Hardness: 65HRC Dimensions: $100^{l}\times5^{t}\times30^{h}$ mm			

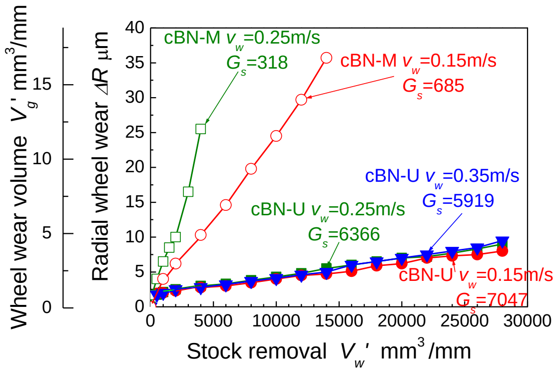


Figure 3, Changes of radial wheel wear ΔR with increasing cumulative stock removal V_w'.

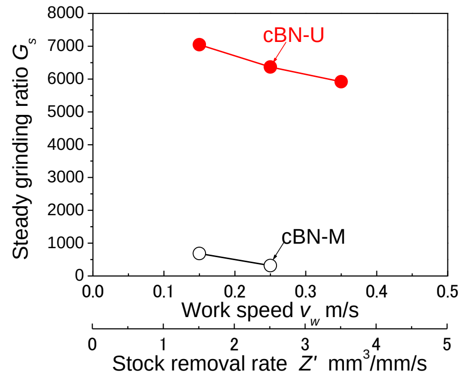


Figure 4, Comparison in steady grinding ratio G_s between cBN-U and cBN-M wheels.

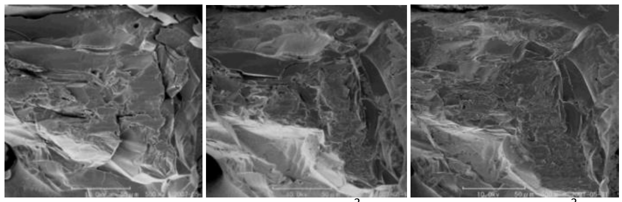
3. Results and discussion

Figure 3 shows the changes of radial wheel wear ΔR with increasing cumulative stock removal V_w' in grinding processes with cBN-U and cBN-M wheels. In the case of a cBN-M wheel, wheel wear increases rapidly with increasing V_w' and is strongly affected by work speed. In contrast, wheel wear of cBN-U wheel is very less than that of the cBN-M wheel and at a work speed v_w ranging from 0.15 to 0.35 m/s, is hardly affected by v_w. In all cases, after grinding a stock removal of about 500 mm³/mm, wheel wear volume increases almost in proportion to the stock removal. The inclination of the straight line in this steady-state wear region, namely, the wheel wear volume per unit stock removal, is defined as the volumetric wheel wear rate r_g. The values of r_g for the cBN-U wheel are much lower than those of conventional cBN-M wheel. The values of the steady grinding ratio G_s, defined as the reciprocal of r_g, in grinding with the cBN-U wheel, are more than 10 times of those in using the cBN-M wheel, as shown in **Figure 4**.

Figure 5 shows typical SEM images of grit cutting edges on the wheel working surfaces after dressing and grinding. Wear mechanism of the cBN-M wheel is mainly based on fracture-wear as well as attrition wear of grits, as grasped in fig.5 (a). It is difficult to grind a stock removal of 500 mm³/mm and more using the cBN-M wheel at work speed 0.35 m/s, because of its heavy wheel wear. In contrast, wear mechanism of the cBN-U wheel is dominantly based on the mixed behaviour of micrometer-sized fracture-wear and minor attrition wear of cutting edges, as shown in Fig. 5 (b). The difference in grinding ratio between cBN-U and cBN-M wheels is mainly caused by the difference in such wear mechanism of grit cutting edges between both wheels [2].

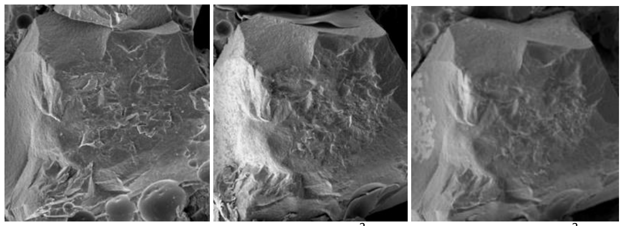
Figure 6 shows the changes of finished surface roughness with increasing V_w'. In all cases, surface roughness increases with increasing V_w'. Its increasing rate in the cBN-M wheel is much higher than that of the cBN-U wheel. For instance, if the threshold value required for the surface roughness is 3 µm in *Rz*, the cumulative stock removal to be able to maintain a roughness lower than the threshold value is "grinding wheel life," which is denoted by V_{wl}'. V_{wl}' in grinding with the cBN-U wheel at work speed 0.15 m/s is about 26000 mm³/mm, as shown in Fig.6. In contrast, V_{wl}' in grinding with the cBN-M wheel at same conditions is about 8000 mm³/mm. V_{wl}' in using cBN-U wheel is longer than 3 times of that in using the cBN-M wheel. The difference of grinding wheel life between cBN-U and cBN-M wheels increases as grinding conditions become severe.

4. Conclusions



(1) After dressing (2) V_w'= 2000 mm³/mm (3) V_w'= 4000 mm³/mm

(a) Typical grit cutting edge on cBN-M wheel surface --50µm--



(1) After dressing (2) V_w'=12000 mm³/mm (3) V_w'=20000 mm³/mm

(b) Typical grit cutting edge on cBN-U wheel surface --50 µm--

Figure 5, Wear behavior of cBN grit cutting edge(v_w=0.25m/s, a=10µm).

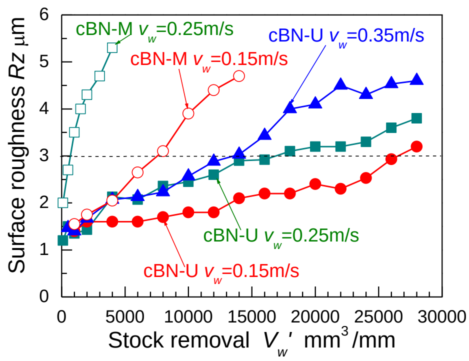


Figure 6, Changes of ground surface roughness with increasing cumulative stock removal V_w'.

The ultrafine-polycrystalline cBN-U wheel has a very high wear resistance as compared with conventional monocrystal-line cBN-M wheel. Hence, the grinding ratio in using cBN-U wheel is higher than 10 times of that in using the cBN-M wheel. The estimated grinding wheel life using the cBN-U wheel, based on the finished surface roughness, is much longer than that of the monocrystalline cBN-M wheel. Wear mechanism of the cBN-U wheel is dominantly based on the mixed behaviour of micrometer-sized fracture-wear and minor attrition wear of grain cutting edges.

References

[1] Ichida Y, Fujimoto M, Inoue Y and Matsui K 2010, *JSME J. Advanced Mechanical Design, Systems, and Manufacturing*, **4**, 5, 1005-14.