Cutting tools from super-hard materials Part II. Blades of regular boron nitride

Narzędzia skrawające z materiałów supertwardych Cz. II. Ostrza z regularnego azotku boru

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The properties of super-hard materials such as diamond and regular boron nitride, and their application on cutting blades. Discussed are examples of blade tools from these materials in the aspects of production process efficiency and economical advantages gained by using these tools. The first part of the article deals with materials and tools with diamond blades and the other – with the blades of a regular boron nitride.

KEYWORDS: diamond, boron nitride, tools, cutting

Regular boron nitride is the second super-hard material, besides diamond. It does not occur in nature. It is artificially produced in synthetic processes similar to those, in which diamonds are produced – at high temperature and under high pressure, in the presence of catalysts. It can crystallize in the wurtzite type and in the hexagonal lattice BN_4. At 1200°C and under > 4 GPa pressure, in boron nitride there is a phase transition into a regular, spatial, flat BN_r lattice, thus similar to the diamond. Boron nitride has a similar density and only slightly less heat conductivity than diamond. Because of the complex synthesis and sintering process, regular nitride boron blades are as expensive as diamonds, and even up to 30% more expensive.

Regular boron nitride has many positive properties, especially when compared to diamond. Its advantages include:

- very high hardness ≤ 6000 HV,
- very low reactivity with most workpieces, including iron,
- high temperature resistance up to 1400°C,
- very high thermal conductivity λ = 60÷120 W/(m·K),
- small coefficient of thermal linear expansion $\alpha = 2.8 \div 3.2 \cdot 10^{-6}$ /K,
- to a large extent, the isotropic mechanical properties of sinter,
- possibility of using coolant,
- possibility of shaping the multisite, monolithic interchangeable tiles,
- possibility of gearing up [4].

This material also has disadvantages, for example:

- high fragility,
- not very high bending strength $R_g < 1000$ MPa, although about 10÷30% higher than ceramic and 350% higher than diamond,
- the need to use shredding rakes (protective flaps) or small rounded edges along the cutting edges, protecting them from crumbling (fig. 4),
- very difficult machinability,
- high price.

These BN properties should be considered as indicative only. They largely depend on the sintering composition, especially on the type of bonding phase, especially when it is a ceramic that increases the resistance to chemical wear. The binder phase can also be cobalt to improve bending strength and fracture resistance [14]. The content of regular boron nitride in certain types of sinter can fluctuate within 25÷95% graphite [11]. In addition, some properties – such as linear extensibility and thermal conductivity – change with temperature, and sometimes it is quite significant. Thus, the physicochemical properties of the super-hard sinters in different sources differ from one another.

The indicative influence of BN content on its cutting properties and other physical properties is presented in fig. 1 and fig. 2.

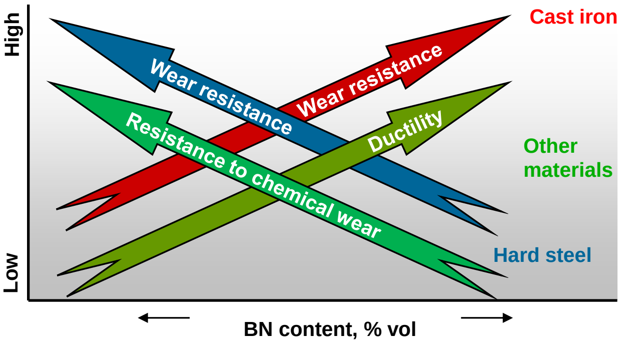

Fig. 1. Effect of BN content on its cutting properties [15]

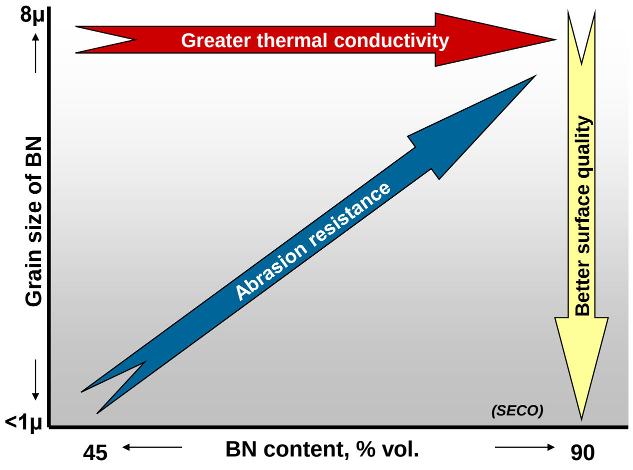

Fig. 2. Dependence of selected properties of sintered boron nitride from grain size and its volume content

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The most important feature of BN, besides its high strength, seems to be that there is no iron affinity, which makes it suitable for use in the processing of steel and cast iron, and therefore of the basic construction materials of machine elements. Due to the very high hardness and associated abrasion resistance (several times that of sintered carbides) and high temperature resistance, it is an ideal material for hardening (55÷68 HRC) hard materials, hard materials, powdered metals or wherever long shelf life is required, such as in large surface finishes, where replacement of the tool during cutting may inadmissibly interfere with their geometry.

If the economic efficiency of the treatment is more important than the very long shelf life, you can rationally increase the cutting speed with the BN tooling tools – up to 5 times as much as the carbide blades.

Due to the very high temperature resistance of BN sinter and the maintenance of good mechanical properties at high temperature, it is recommended to use these materials at 700÷800°C when the hardness of the workpieces is much lower than the hardness of the sinter (fig. 3).

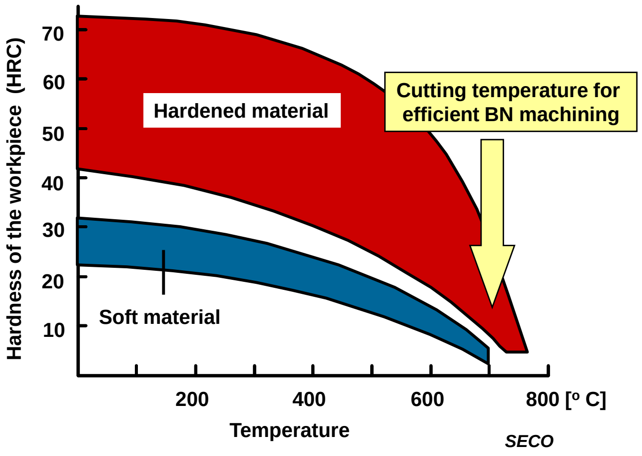

Fig. 3. Dependence of workpiece hardness on temperature

Regular boron nitride is used most often in very difficult processing conditions when the material is very hard cut, cutting is carried out at high speeds, and even when the work is impacted. The very high hardness of the BN sinter results in its low impact strength, hence the need to protect the blade from being crushed. This is used to round the edges of the cutting edges with a small radius r_n and/or shear of the rake surface, commonly known as the protective chamfer (fig. 4).

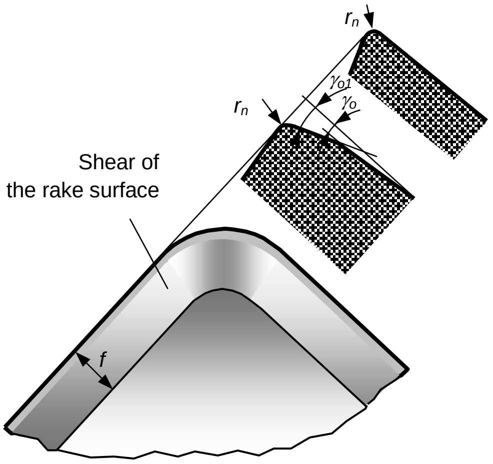

Fig. 4. Examples of protection of BN blades from cutting off the cutting edges

The shear width and rake angles y_o and y_{o1} depend on the operating conditions of the blade. The heavier ones are, the wider the chamfers and the more negative angles of attack. Most often they have: width f = 0.2 mm and angle y_{o1} = -20°. For lighter work conditions and where small cutting forces are required, blades with positive rake angles y_o and no protective shears are used.

- simplification of technology (eliminating the heat treatment operations and associated inter-departmental transport from the middle of the technological chain),
- possibility to apply complete machining (the whole process takes place on one machine),
- greater volume efficiency and cost-effective cutting compared to grinding,
- less nuisance to the environment due to the lack of machining fluids,
- machine tools for machining are much cheaper than grinders,
- smaller machine park (less or no grinding),
- trochoidal cutting technologies reduce the cutting temperature,
- greater accuracy of dimensional surface machining (due to the possibility of reducing the number of operations – object friction),
- greater flexibility of the process compared to grinding,
- shorter t_{pz} (preparatory-finishing) and t_{wn} (tool change) times, for easier machine tool changeover if cutting tools are used rather than abrasive tools and grinders,
- greater possibilities for cutting tools as compared to abrasive tools due to: the ability to use multiple tools on a single machine more frequently and simpler regeneration by changing/replacing the cutter corner,
- during turning, external and internal shapes can be made on the same machine, and in the case of grinding, it is not always possible; this may lead to a reduction in the number of operations and an increase in the accuracy of the machining of coupled surfaces.

Examples of tools with blades of regular boron nitride

Blades of regular boron nitride and with so called Xcel geometry, allow at the flowrate $\leq$ 0.4 mm to achieve a surface roughness of R_z < 6.3 μm, thereby reducing machining time by up to 50% (fig. 5).

Even materials with very good cutting properties, such as BN, are protected with protective coatings. An example of turning machining with such blades is shown in fig. 6.

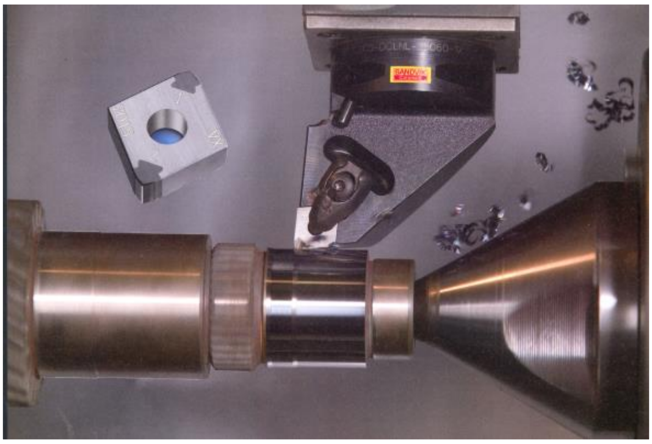

Fig. 5. Example of machining a hardened shaft with BN blades [14]

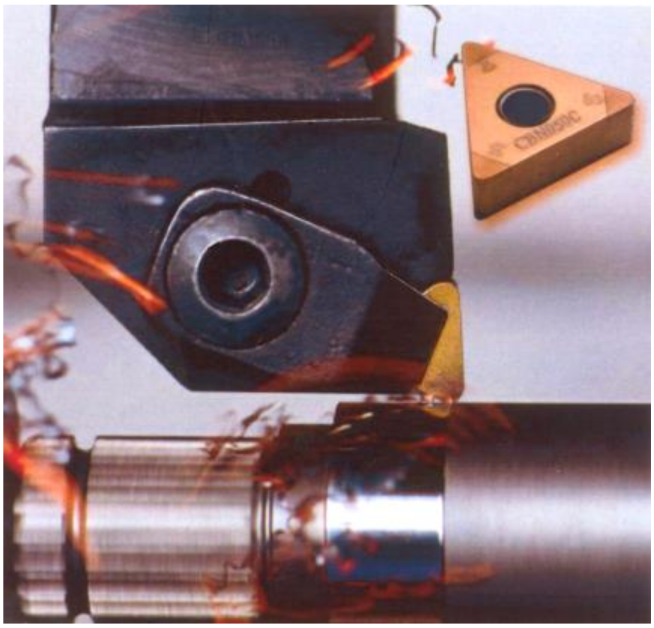

Fig. 6. Example of high-performance turning using tool with BN insert in Secomax CBN050C type coated with PVD-Ti, Si-N and conditioned edges [15]

Fig. 7. Examples of products for the automotive industry and tools with BN blades for shaping in the hardened state (Gühring)

In fig. 7, there are examples of tools – cutting inserts with BN blades – and products, the complex surfaces of which are shaped with these tools.

Fig. 8 shows a bell cutter for circular milling of external surfaces. Characteristic rings strengthening and stiffening the structure can be seen. They allow for increased rotational speed and better machining accuracy. The bell system of the structure increases the cutting efficiency also because the blades in such tools have a higher path of peripheral contact with the workpiece than the classic external cutter. However, such milling structure complicates, and sometimes even prevents the final shaping of cutting edges due to difficult access to them. One possible solution to this problem may be the use of a collapsible structure in which the stiffening rings are mechanically fixed (fig. 8).

Fig. 9 shows Mapal BN reamers for small hole drilling in hardness steels of 60 HRC. These tools are offered with diameters in the range 1÷10 mm. It is worth noting that in the case of very small tool diameters, when there are brazing difficulties of the blade segments, the whole ends of these super-hard tools are sintered not to the sub-plate (fig. 3 in [19]), but directly to the carbide tool body (fig. 9).

Fig. 8. Example of BN ring cutter for shaping in hardened state (Gühring)

Fig. 9. BN reamers for machining small holes (Mapal)

Super-hard tools often shape surfaces, where high accuracy is required. Sometimes, even after tens of thousands of objects, a sufficient surface quality is maintained, but the dimensions begin to approach the tolerance limits. The dimensional correction of the tool can then be accomplished by moving the cartridge cassette itself (figs. 16, 18, 19 in [19]) or elastic deformation of the body – as shown in fig. 10. By screwing the conical head into the body with a ruler, it is easy to make minor adjustments to the diameter of the reamer several times, greatly extending its useful life. Such regeneration does not require specialized sharpening, often combined with blade replacement.

Fig. 10. Reamer with adjustable diameter (Gühring)

Regeneration of tools

Round plates, including super-hard materials, can be fastened to the tool-holder slots in multiple angular positions, resulting in a high number of edge regeneration. This facilitates the mechanism shown in fig. 11 for indexing the angular position of the blade. The knob at the bottom of the tool makes it easy to maneuver with a hot plate, which is intensively heated, especially when it is made of BN sinter, which has an extremely high thermal conductivity.

Fig. 11. Turning knives with a mechanism for fixing and angular indexing of circular tiles (Mapal)

Blade tools of super-hard materials can be regenerated. If the blades are placed in standard removable plates – such as used in turning lathes, drill bits or milling heads – it is easy to restore the cutting properties by turning or replacing the plate, and it costs little more than one corner. The tool regeneration process, in which the blade segments are soldered, typically consists of the worn blades being replaced by new ones, and only the tool body is recovered. It is expensive and can cost as much as 60% of the price of a new tool, but produces a product with almost the same functionality as before regeneration. Due to the wiping of the body and some degree of wear of the grip, such regeneration is usually not more than 2 to 3 times. Also note that the progressive wiping process between the blades and the tool body can lead to a deterioration of the dynamic balance, which is important since such tools typically operate at very high rotational speeds.

The image of a multi-stage deep dredging with super-hardened sintered blades and clearly visible traces of the tool body wreckage – after processing several hundred thousand objects and multiple regeneration – is shown in fig. 12. Thus, not only after the new tool is made but also after each restoration of its properties A dynamic balancing should be performed.

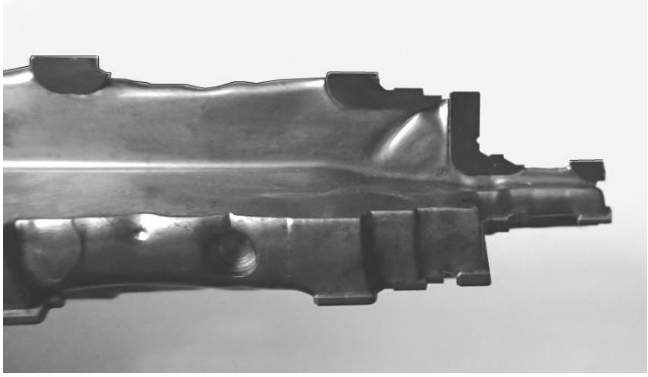

Fig. 12. Traces on the tool body due to diamond-tipped blades after processing several hundred thousand objects (according to Mapal)

The very small radial and axial run-outs of the cutting edges play an important role – not only in the quality of surfaces formed by the tool but also in the durability of these tools. With brazed plates it is provided by fine sharpening. Whereas, where blades are intended to replace interchangeable plates, it is very advantageous to mount them in cartridges that can be precisely adjusted to the size, e.g. as shown in fig. 18 and fig. 19 in [19].

In reamers, including multistage (e.g. fig. 9 in [19]), diamond sintered guide bars are most commonly used. Regeneration of such tools includes, in addition to replacing and re-sharpening the blade segments, also analogous regeneration of the guide strips.

Multi-blade tools, if they are so called folded tools, i.e. with mechanically fixed blades, are re-generated – as mentioned – by changing the corner of the replaceable plate, usually multi-edge. Even such regeneration variants are possible to replace only the blades that were worn leaving them with little wear [5]. A similar way of regenerating the tooling tools, but with respect to tools with solder blades, can be transferred to this tool group. In this case, tools can be divided into sections, where the blades wear with varying intensity. Then, by regenerating the tool, only the part is replaced, not the whole tool. Such re-generation is definitely cheaper, faster and can be made by the user using the tool parts provided by the tool manufacturer.

Example of such a tool, regenerated according to the described strategy, is shown in fig. 13. It consists of 2 separate segments.

Fig. 13. Example of 2-section cutter (Gühring)

If the brazed blade tool is not split into separate sections, it usually cannot be regenerated by replacing the worn blade. This is due to the danger of breaking the position of the remaining blades during heating of the tool body that is necessary to de-sold the replacement blades.

Condition of the partial regeneration of the tool is to provide a sufficiently precise or adjustable connection of its segments.

The economical efficiency of cutting blades made of super-hard materials

Blades of sintered diamond or regular boron nitride are several times more expensive than blades from other tool materials such as sintered carbide, cermet, or ceramics. This results from a much more complex, technically more difficult process of producing the material itself, as well as extremely costly blade shaping, surface finishing and cutting edges. Laser, electro-erosion, electrochemical treatment as well as conventional and unconventional abrasives, including electrochemical and electro-erosion assistance, are used for this purpose.

Despite the high price of super-hard materials, the cost-effective economics of using blades from these materials can be considerably higher compared to cutting tools with blades from other, much cheaper tool materials. This is due, among others, to:

- the possibility of significantly increasing the machining efficiency, especially the cutting speed,
- definitely greater tool life,
- less frequent downtime of machine tools needed to replace and set tools,
- the possibility of limiting surveillance to detect the moment of tool shredding, assessing the quality and accuracy of shaped surfaces, etc.

When talking about the possibility of increasing the efficiency of a cutting machine, it would be worth mentioning of other influences that affect it, including those related to tools, not necessarily with super-hard materials [5–7]. There may be mentioned, for example, the replacement of several commercial tools with one special, multi-tool assembly (e.g. figs. 8, 10, 12) in the technological processes of mass production. This is usually supported by the use of blades from super-hard materials. This allows to shorten the machining time, combine the treatments performed on several machines in one operation and get, among other things, release personnel and production capacity for other tasks or reduce the investment costs of starting a new production.

Depending on many factors – such as the value of the allowance, the length of the cutting path, the type and structure of the workpiece, or the type of blade material – the machining time of one object with the super-hard tool may vary but is usually very short. Assuming that, on average, the machining time with the DP blades of an aluminum-silicon alloy object is several seconds, and assuming that the number of workpieces during its shelf life can range from several dozen to several hundred thousands, then the machining cost for one item can be reached with a tool price of 8,000 PLN, just a few cents. In average production conditions, it is significantly lower than that of other blade materials such as sintered carbide.

Due to the high unit price of super-hard tool blades, stable machining process and low probability of catastrophic blade damage are a precondition for high efficiency.

REFERENCES

1. Bakul W.N., Zacharienko I.P., Kunikin J.A., Milszttejn M.Z. *„Ostrzenie narzędzi ściernicami diamentowymi”*. Warszawa: WNT, 1975.
2. Dobrzański L.A. *„Materiały inżynierskie i projektowanie materiałowe”*. Warszawa: WNT, 2006.
3. Dobrzański L.A. *„Podstawy nauki o materiałach i metaloznawstwo – Materiały inżynierskie z podstawami projektowania materiałowego”*. Warszawa: WNT, 2002.
4. Dopierała A. „KD1405 – czysty diament polikrystaliczny”. *Mechanik*. 12 (2004): pp. 804–805.
5. Cichosz P. *„Efektywność kształtowania skrawaniem przedmiotów osiowosymetrycznych w zintegrowanym wytwarzaniu”*. Wrocław: Oficyna Wydawnicza PWr, 1998.
6. Cichosz P. *„Narzędzia skrawające*”. Warszawa: WNT, 2006.
7. Cichosz P., Kuzinovski M. *„Ekonomiczne aspekty doboru narzędzi skrawających do zadania produkcyjnego. Obróbka skrawaniem – wysoka produktywność”.* Wrocław: Oficyna Wydawnicza PWr, 2007.
8. Jaworska L. *„Diament – otrzymywanie i zastosowanie w obróbce skrawaniem”*. Warszawa: WNT, 2009.
9. Legutko S. „Materiały narzędziowe w obróbce skrawaniem”. *Mechanik*. 12 (2004): pp. 835–841.
10. Materiały informacyjne firmy DMG MORI.
11. Materiały informacyjne firmy Element Six.
12. Materiały informacyjne firmy Gühring.
13. Materiały informacyjne firmy Mapal.
14. Materiały informacyjne firmy Sandvik Coromant.
15. Materiały informacyjne firmy SECO.
16. Materiały informacyjne firmy TIZ TOOLS.
17. Stobierski L. (red). *„Spiekane materiały narzędziowe przeznaczone na ostrza narzędzi do obróbki z wysokimi prędkościami skrawania*”. Kraków: Wydawnictwo Naukowe „Akapit”, 2014.
18. Wysiecki W. *„Nowoczesne materiały narzędziowe”*. Warszawa: WNT, 1997.
19. Cichosz P., Kuzinovski M., Tomov M. „Narzędzia skrawające z materiałów supertwardych. Cz. I. Ostrza diamentowe”. *Mechanik*. 8–9 (2017): pp. 660–668.

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