CONSIDERATIONS ABOUT MACHINING WITH SUPERABRASIVE MATERIALS

Cristian PISARCIUC¹, Gheorghe OBACIU²

ABSTRACT:
In this paper are presented the intrinsic properties of superabrasive materials as appropriate to the requirements of the today manufacturing. A number of studies are given where superabrasive materials are utilised in industry. A number of new superabrasive material products are also discussed and their likely impacts on increasing even further the use of such kind of materials. In addition, this paper delineates the role of PCD and cBN tools in the area of machining of new materials with relevant inputs from the literature.

KEYWORDS superabrasive materials, superalloys, PCD and cBN cutting tools, high-speed machining, cutting forces

1. INTRODUCTION
The modern industry requires manufacturing methods which are extremely precise. The mechanism of material removal has to be very controlled so that negligible stress is left in the surface the component being machined. Often this is required when machining materials which are classified as difficult to machine and/or in an environment where little or no coolant is permissible. Machining techniques using PCD/PCBN and cBN/diamond are particularly suited to these types of machining problems. When machining issues are raised, the subject of superalloys is usually the first to be mentioned. This is not surprising that after their initial development, these materials remain difficult to machine, with no one particular group of machining tool materials being firmly recognised as first choice (cutting or grinding). These materials are used for components that are exposed to a combination of high dynamic stresses and high operating temperatures, and are typically titanium and nickel based alloys. Production methods play a key role in terms of the functionality and reliability of the finished component. Modern cutting materials and abrasive types allow increased productivity through high stock removal rates and close tolerances. The precondition for exploiting this performance potential is a careful matching of the properties of the component with the machining conditions and the tool characteristics. This requires precise knowledge of the specific wear and performance behaviour of the tool materials. Manufacturing industry is not confined to superalloys, as a wide variety of materials are commonly employed. Aluminium alloys, carbon fibre, glass reinforced plastic, hardened steels and matrix-metal composites (MMCs) are also widely or increasingly being used. Superabrasive materials machine these products extremely well.

2. SUPERABRASIVE MATERIAL PROPERTIES

2.1. Diamond Cutting Tools
Edge sharpness and its retention are main advantages of diamond cutting tool products. Machining of fibrous (plastics, GRPs, carbon fibre, acrylics) and composite materials requires a clean and accurate cutting to avoid 'plucking' of the fibres from an adjacent workpiece. The availability of polycrystalline diamond (PCD) in a number of grades, Chemical Vapour Deposited (CVD) thick film and synthetic single crystal diamond enables a range of edge qualities to be obtained. Figure 1 gives an example of these edge qualities, although it should be noted that methods of edge preparation and the process time devoted to edge preparation vary. From figure 1 it can be seen that CVD diamond
materials can produce edge qualities better than fine grained PCD [1]. The single crystal synthetic diamond has an edge quality similar to CVD diamond.

The data from figure 1 was generated on a tool and cutter grinding machine, but the use of a scaife polishing wheel would enable further improvement in the edge quality of, in particular, single crystal synthetic material. Traditionally the best edge quality has been achieved with ultra fine grain carbides or high speed steel tools. The introduction of CVD and single crystal synthetic diamond has significantly improved edge quality capabilities with diamond based tool materials.

2.2. Polycrystalline Cubic Boron Nitride (PCBN)

Structures of diamond and cBN are similar, as shown in figure 2. In both cases, each of the atoms in the structure is bonded to four others with perfectly tetrahedral arranged bonds (bond angle 109° 28').

For diamond, each carbon atom is bonded to four other carbon atoms with pure covalent bonding [2]. In the case of cBN, the bond is predominantly covalent, but because boron and nitrogen are dissimilar atoms, there is a small degree of ionic bonding. In cBN, each nitrogen atom is bonded to four boron atoms and, in turn, each boron atom to four nitrogen atoms, in a tetrahedral manner.

The crystal morphology of synthetic diamond can range from a pure cube to a pure octahedron, depending on the relative rates of growth of the crystal faces along the main crystallographic directions. This, in turn, can be manipulated by the synthesis process conditions.

A range of crystal forms can, therefore, exist between the two extremes of the cube and the octahedron (fig. 3).

The morphology of cubic boron nitride is more complex than that of diamond. Both have the same atom-to-atom geometric structure (based on the diamond structure itself) but in the case of cBN there is a loss of symmetry because of the fact that the atoms alternate between boron and nitrogen. In diamond, the octahedral crystal faces are chemically identical. In cBN, the eight octahedral crystal faces are of two different types, with four faces being terminated with boron and four faces terminated with nitrogen. If the growth rates of these two types of octahedral faces are equal, then an octahedron will result (fig. 3). If one type grows to the exclusion of the other, then the result will be a tetrahedron. It has been an observation thus far that tetrahedra is most commonly of the type terminated with nitrogen atoms [3]. The morphology of a cBN
particle can therefore vary between cubic and octahedral (similar to that of diamond), and also between octahedral and tetrahedral (fig. 3).
The synthesis conditions to produce these products have been selected such that each falls into a different domain in the morphology chart. This chart shows part of the range of possible morphologies and also the areas where these materials lie. This affects the way in which they fracture, which in turn affects their behaviour during use.

Resulted from physical characteristics, the thermal stability of PCBN is an important attribute for the machining of high allied work pieces. As these materials have good high temperature strength, they do not soften during cutting in the same way as steels. Cutting interface temperatures remain high, and the same, workpiece hardness, thus hardness of PCBN is crucial in obtaining improved performance.

The high compressive strength that PCBN exhibits assists also in edge stability. Again, this is particularly important when machining superalloys which, in addition to their high temperature strength, have a predisposition to work harden during machining. This work hardened region imposes a high level of stress on the tool cutting edge, so good edge stability is important. Finally, chemical wear mechanisms, both diffusive and adhesive, are known to occur when machining superalloys. PCBN products are generally chemically inert and exhibit good resistance to these types of wear.

3. GRINDING WHEEL PRODUCTS

During the grinding operation, material removal rate, surface finish, material integrity, wheel life and dimensional tolerances are some of the more important factors which are considered. In terms of the abrasive, these factors can be influenced by such characteristics as hardness and abrasion resistance, hot hardness, fracture mode, thermal conductivity and chemical reactivity. In grinding difficult to machine materials, particularly where the dimensional and material integrity considerations are of great importance, a high performance super abrasive such as cBN has the potential to be the ideal material. The hardness of cBN is second only to that of diamond and well above that of the conventional abrasives. This gives it superior resistance to abrasion. Its thermal conductivity at room temperature is also the highest known except for diamond which, in turn, means that heat generated in the grinding zone is conducted away by the cBN, resulting in lower grinding temperatures being produced. Finally, cBN is resistant to chemical attack. Hence, in demanding applications, these properties provide the potential solutions to many grinding problems.

In addition to these basic properties, because cBN is a manufactured material, other characteristics can be incorporated, in particular, particle impact strength and fracture properties. High strength monocrystalline particles tended to be very blocky in shape and had a characteristic fracture pattern whereby small fragments tended to break away from around the periphery of the particle. More recent cBN products have high strength and thermal stability together with a more angular characteristic particle shape, and fracture in a micro-cleaving mode to leave very sharp angular cutting points which are more efficient in the chip removal process. This, in turn, leads to lower grinding power being required and good free-cutting behaviour. In the past, to gain free-cutting characteristics, friable abrasive could be used which fractured at relatively low grinding loads and thus was able to maintain low grinding power. High strength cBN particles could wear to form wear flats which could give rise to higher power (and temperatures) being generated.

In conclusion, cBN products have the capabilities to maintain high strength and to absorb loads generated in metal removal process, but the sharp, angular shape of the particles ensures that this is achieved with minimum grinding force. Figure 4 shows an example of a high strength, sharp, angular cBN material (ABN 600, De Beers Industrial Diamond Division) [4]. ABN600 present high-strength abrasive potential and is commonly used in conjunctions with metal bond. The wear mechanisms associated with the cBN particles in this type of product ensure good grit protrusion from the wheel bond (due to the high impact strength), which is important for high stock removal rates and allows sufficient chip clearance between the
wheel and the workpiece. In addition, these particles exhibit a sharp, angular chipping wear characteristic, which ensures that a free-cutting action of the wheel is maintained during operation.

Fig. 4. Particles and fractured particles of ABN600

4. GRINDING OF NICKEL BASED SUPERALLOY

Materials such as Inconel [5] (nickel-chromium alloy) are relatively hard and ductile. These have a tendency to work harden, and can, during grinding, clog or load a grinding wheel, which in turn leads to poor wheel performance and workpiece burn. One option that of continuous dressing, can alleviate wheel clogging to an extent, but also contribute to high wheel wear.

The grinding of Inconel with conventional abrasive wheels has traditionally meant using a relatively low wheel speed and low material removal rates, and also poor wheel performance. There are, however, some recent developments in this technology which have resulted in significant improvements in performance. However, the area is one of considerable potential for cBN grinding and this has led to the evaluation and successful development of a number of grinding methods for high performance alloys using cBN abrasives. In studies of the surface grinding of Inconel 718 [6], cBN wheels produce lower grinding forces and with a significant increase in wheel life compared with conventional abrasive wheels [7]. Typical steady state grinding forces and relative wheel wear in the surface grinding of Inconel with wheels containing cBN and conventional abrasive are shown in figures 5. The other benefits derived from cBN wheels in the surface grinding of Inconel are improved surface finish and increased dimensional accuracy.

As referred above, one of the limiting factors in the grinding of high performance alloys is workpiece burn caused by temperature build-up in the working zone of the wheel, which is particularly apparent in deep grinding.

Fig. 5. Grinding forces in surface grinding Inconel

Higher working temperatures in deep grinding processes are generally due to a larger contact length between the wheel and the workpiece and higher material removal rates. The factors [8] which need to be considered to reduce the risk of workpiece burn are:
- The selection of abrasive and wheel design to ensure adequate chip clearance and to minimise bond rubbing with the workpiece;
- Wheel dressing parameters which ensure good particle protrusion and an open wheel surface;
- Coolant type and coolant delivery which necessitates a high pressure, high velocity coolant stream;
- The grinding parameters to be used.

In studies of the high efficiency deep grinding of Inconel, it was found that the workpiece temperature was significantly lower with cBN wheels than with aluminium oxide wheels, as can be seen in figure 6, with no unfavourable effects on surface finish. Numerous examples in industry have shown that cBN provides superior performance to conventional abrasives in the grinding high
performance alloys used in industry. While these alloys remain difficult to machine, cBN, with its extreme hardness and excellent thermal conductivity, provides a practical solution to grinding such materials, both in deep and surface grinding applications. Careful consideration is necessary, however, in order to optimise performance and reduce the risk of wheel clogging and workpiece burns, which are characteristic of the machining of these materials, both in deep and surface grinding applications.

![Fig. 6. Workpiece surface temperature when deep grinding of Inconel](image.png)

5. CONCLUSIONS

This paper has illustrated the benefits of PCBN and cBN when grinding and machining superalloys, including improved tool life, higher productivity, improved surface finish and lower machining forces. In addition, benefits can also increase by employing PCD in rotary tooling when machining specialty plastics and composites, where edge quality and abrasion resistance combine to give excellent performance. This is similarly the case in the machining of acrylic plastics, where PCD and single crystal synthetic diamond complement each other perfectly to produce benefits in precision, productivity and the service life of components. However, superabradive grinding and cutting tool materials have certainly not reached their full potential in their application and the challenge for the superabradive industry for the future is to find ways whereby this potential can be realised.

From a material point of view, diamond and cBN abrasive developments have been impulsion largely by the needs of the automotive and allied volume production industries, where manufacturing throughput and tool cost dominate. The key workpiece material types have included the hard ferrous materials, aluminium alloys and non-ferrous composites, and the machining operations which go with these have dominated development objectives.

REFERENCES


AUTHORS

1. Assoc.prof.dr.eng. Cristian PISARCIUC, Transilvania University of Brasov, Romania, pisarciuc.c@unitbv.ro
2. Professor dr.eng. Gheorghe OBACIU, Transilvania University of Brasov, Romania, g.obaciu@rdslink.ro